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# Proceedings of the Seminar on Rail Freight Research & Development

Montreal, Quebec
June 12–13, 1986

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# PROCEEDINGS OF THE SEMINAR
# ON
# RAIL FREIGHT RESEARCH & DEVELOPMENT

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Edited by

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Un sommaire en français de ce compte rendu est inclus avant la table des matières.

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17. Abstract

This report contains the papers presented at the Seminar on Rail Freight Research and Development held in Montreal on June 12 and 13, 1986, and sponsored by the Transportation Development Centre (TDC) of Transport Canada in cooperation with the Railway Advisory Board of the Railway Association of Canada. The papers deal with a portion of the work done in the four major areas of R&D embraced by the TDC Rail Freight R&D Program, viz. motive power, freight cars, track, and signalling and communications.

Also included in the report are the proceedings of the Railway Advisory Board meeting held on the second day of the seminar, at which the papers presented on the previous day were reviewed and potential future courses of cooperative rail freight research discussed.

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17. Résumé

Compte rendu des mémoires soumis lors du séminaire sur la R&D en transport ferroviaire de marchandises, tenu à Montréal les 12 et 13 juin 1986 et parrainé par le Centre de développement des transports (CDT) de Transports Canada avec la collaboration du Comité consultatif du transport ferroviaire de l'Association des chemins de fer du Canada. Les exposés traitent d'une partie de la recherche lancée dans les quatre grands domaines du programme de R&D du CDT sur le transport ferroviaire de marchandises, à savoir: matériel de traction, matériel marchandises, infrastructure et voies ferrées et, enfin, installations de sécurité.

Compte rendu également de l'assemblée publique du Comité consultatif du transport ferroviaire qui a eu lieu dans la matinée du deuxième jour, et au cours de laquelle s'est faite la revue des mémoires présentés la veille, suivie d'un débat sur la forme que pourrait revêtir la recherche coopérative en matière de transport ferroviaire de marchandises.

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# FOREWORD

The Seminar on Rail Freight Research and Development was held in the Conference Centre at the Guy Favreau Complex, Montreal, Que., on June 12 and 13, 1986. The seminar was sponsored by the Transportation Development Centre (TDC) of Transport Canada, in cooperation with the Transport Canada/Railway Association of Canada Railway Advisory Board (RAB).

In the 15 years since its formation, TDC has funded some 275 rail freight R&D projects. The principal objective of the seminar was to bring the contents of the technical reports prepared on these projects, particularly those completed during the past five years, to the attention of a larger segment of Canada's scientific community and railway operating personnel. The secondary objective was to obtain feedback on the usefulness of such government industry cooperative research, and recommendations regarding future work that might be undertaken. Both of these objectives were achieved.

Attendance on the first day of the seminar was 170 - considerably more than the expected 125-150. Analysis of the completed seminar evaluation forms showed that 60% of the respondents gave the seminar an overall rating of 80% or higher. All of the respondents favoured the holding of future rail freight R&D seminars, most of them suggesting a one-year frequency.

TDC expresses it thanks to all the seminar participants. Particular thanks are due to Mr. P.J. Detmold who served as Seminar Chairman, to the four railway officers who chaired the individual technical sessions, and to the 25 speakers from industry and government whose papers are reproduced in these Proceedings.

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# SUMMARY

## 1. INTRODUCTION

The Seminar on Rail Freight Research and Development was held in the Conference Centre at the Guy Favreau Complex, Montreal, Que., on June 12 and 13, 1986. The seminar was sponsored by the Transportation Development Centre (TDC) of Transport Canada, in cooperation with the Transport Canada/Railway Association of Canada Railway Advisory Board (RAB).

Rail freight research and development has always been an important part of TDC's overall program. Of particular importance has been the five-year (1981-1986) Augmented Rail Freight R&D Program (ARFP) for which total expenditures, including those made by Canadian railways and suppliers, have exceeded $14 million. Including the ARFP, TDC has funded some 275 rail freight R&D projects since its formation in 1970, of which approximately 240 have so far been completed. Each completed project has been documented by a technical report. Copies of the reports have been distributed to researchers, other individuals and libraries.

The primary objective of the seminar was to bring the large body of information contained in these technical reports to the attention of a larger segment of Canada's scientific community and railway operating personnel, thereby directly enhancing its benefit to the railway industry, and indirectly, to Canada as a whole. The secondary objective was to obtain opinions regarding the usefulness of cooperative research such as has been carried out under the program, and recommendations as to the nature of future work that might be undertaken.

## 2. PROCEEDINGS: THURSDAY, JUNE 12

The seminar delegates were welcomed by Mr. P.J.Detmold, Chairman of the RAB and Seminar Chairman. In his brief remarks, Mr. Detmold emphasized the importance of cooperative research to ensure that new products developed are satisfactory for use throughout the entire continental railway system. To be satisfactory, products must be "standardized" and this can be best achieved through participation by, and cooperation between, all parties. Cooperative research is required. He also underlined the need for the industry to look ahead in order to identify the products and systems that will be needed in the future, and to define the process for ensuring that they will be available when needed. The supply industry, Mr. Detmold pointed out, must be included in the planning, if the time and performance criteria are to be met.

Upon conclusion of his remarks, the Chairman introduced Mr. N.E.Rudback, Executive Director of the Transportation Development Centre.

Mr. Rudback welcomed the delegates on behalf of Transport Canada. He noted that although TDC's rail freight R&D program to date has been aimed principally at increasing productivity and encouraging development, certain of that work has yielded increased safety as a by-product. In the near future at least, budgetary constraints will impact on the size of the program nd all proposed work will have to be even more carefully justified. The nature of the program, too, is changing, he said. Future work will be aimed more directly at increased safety with increased productivity as a by-product.

Mr. Rudback's remarks were followed by an overview of the Rail Freight Research and Development Program by the TDC officer responsible for its implementation, Mr. W.S.C.McLaren, Chief of the Current Technology Division of TDC. Mr. McLaren stated that the seminar had been requested by the Director General of R&D for Transport Canada and that, with the exception of the Advanced Train Control Systems project, all the projects to be discussed during the seminar form part of the TDC/RAB Rail Freight Program. He emphasized the cooperative nature of the Program by noting that:

i) six railway companies have participated and contributed resources to the program: CN Rail, CP Rail, BC Rail, Quebec North Shore and Labrador Railway, Ontario Northland Railway and the Cartier Railway Company.

ii) 35 different contractors have been involved in carrying out the work, of which four have made resource contributions.

iii) federal government contributions to the program have been made through the Transportation Development Centre of Transport Canada acting as program manager as well as a program sponsor. Additional contributions to the program have been provided from the National Energy Program, and the Unsolicited Proposal Program. The National Research Council of Canada has contributed substantially to the program through in-kind research contributions.

iv) international collaboration has been achieved through the auspices of the Memorandum of Understanding with the U.S. Department of Transportation (Jamieson/Volpe agreement).

v) coordination with the North American railway R&D effort has been achieved through membership on the Track Train Dynamics Steering Committee and information exchange with the Research and Test Department of the Association of American Railroads (AAR).

Mr. McLaren stated that TDC's Rail Freight R&D Program received a significant boost in 1981 with the start of the ARFP. That program added a total of about $9 million to the TDC rail freight budget over the five-year period ending in 1986, this being a substantial addition to the approximate $1 million which had been available annually from TDC's base budget. He noted further that the time available during the seminar would permit discussion of only some of the more than 80 projects in the ARFP and that information on the remainder of the projects could be found in the registration package given to each delegate.

Mr. McLaren concluded with a short preview of the content of the seminar program for the balance of the day. He also pointed out that the next day's session, an open meeting of the Railway Advisory Board, was expected to give seminar delegates an opportunity to provide feedback on the R&D program.

The remainder of the first day of the seminar was devoted to the presentation of papers in four separate technical sessions - two in parallel in the morning and two in parallel in the afternoon. Each session dealt with one of the four principal areas of the R&D program - motive power, freight cars, track, signalling and communication - and was chaired by a member of the particular Railway Advisory Board Working Group concerned with that area. Each paper described one of the more significant projects within the R&D program. Abstracts of the 25 technical papers are included as Section 4 of this Summary.

## 3. PROCEEDINGS: FRIDAY, JUNE 13

The final seminar session was held on the morning of the second day and took the form of an open meeting of the Railway Advisory Board, chaired by the RAB Chairman, Mr. P.J.Detmold. The content of each of the papers presented on the previous day was reviewed by the respective Session Chairmen. This was followed by an open discussion of various questions raised by Mr. Detmold regarding the overall Rail Freight R&D Program.

The seminar was then declared adjourned shortly after noon.

Following is a distillation of the thoughts expressed by delegates during the open discussion.

### Is cooperative research worthwhile?

The Rail Freight R&D Program as a whole is a cooperative effort of the railway industry through the RAB, and the government. On a different level, various projects within the program have involved competing railways and competing suppliers working together to solve common problems, with TDC serving as a catalyst and providing major financial assistance. Generally, the technical objectives of the individual projects have been achieved, and on that basis, it can be said that cooperative research is worthwhile. However, whether the benefits justified the cost is often not known.

This leads to the question that if the end users of the research results could not see enough benefits to themselves to fund the research, what were the arguments for doing it? How much of the research would have happened in the absence of government funding?

The Advanced Train Control System (ATCS) represents, at least to date, another form of cooperative research; i.e., the sharing of costs and results between the potential beneficiaries, each obviously confident that their benefits will justify their costs. It was noted though, that the genesis of the ATCS project was earlier work funded by Transport Canada, without which, current ATCS development work would probably not be taking place - at least not at this time. In that light, was the cost of the earlier work justified?

It does appear that in the past, some railway research, whether funded by government or industry or jointly, has been undertaken without sufficient effort having first been made to quantify the cost/benefit relationship. However, it does not necessarily follow that, given adequate effort in this respect, and assuming failure to derive a favourable relationship, the proposed work should not proceed. It is not always possible to fully identify future benefits, let alone place a dollar value on them. Development of the laser was an example cited where useful and commercially beneficial applications of that early work were identified and achieved only years later. The decision to proceed, or not proceed, with apparently useful rail freight R&D that cannot be justified by a favourable cost/benefit ratio, should be made by experienced managers representing all parties that might have an interest - railways, suppliers and government - as appropriate. Furthermore and notwithstanding availability of funding for the proposed work, the decision should take into account other demands and priorities for the technical expertise and other resources needed for the work.

**Should there be major railway supplier cooperative program?**

It was noted that the environment for railway suppliers in Canada is different from that in Europe and the U.S. In Europe, the state railways work hand-in-glove with suppliers to develop specific products and systems for their application. In the United States, the free enterprise system works because large supplier organizations there can make substantial investments in R&D and, due to the large market, can be confident of sufficient return on their investment. In Canada, both the supplier organizations and the market are smaller than in the U.S., but product development costs are just as great, all of which inhibits major investment in R&D by a supplier on its own with resultant loss of opportunity for benefits. On the other hand, Canadian developments such as those for rear-of-train telemetry equipment and railway training simulators, made possible by government assistance with R&D costs, are providing benefits not only to the developers, but also to Canadian railroads and, indirectly, to the Canadian economy.

**What types of R&D project should be undertaken?**

- Longitudinal train forces, utilizing the model developed in the Rail Freight R&D program by DSL Dynamic Sciences Ltd. and giving due recognition to work done in that field in the past, particularly that by John Punwani of the AAR.

- Freight car trucks, including wheels and brake system, with the objective of improving performance. In such work, consideration must also be given to initial cost, future maintenance cost and also to the problems that would be encountered with interchangeability of parts in light of the very large number of conventional three-piece trucks now in service on North American railways.

- In the area of data communications:
  - The statistical characterization of channels utilized in applications such as train-to-wayside, end-to-end of train, remote operated power switch and ATCS, in order to better define the modem and the error detection and error correction mechanisms that should be applied against these specific channels.

- In the area of safety:
  - Ways and means to reduce accidents at highway/railway grade crossings;
  - Utilization of simulation techniques for determining dynamic forces in order to reduce train accidents caused by rail rollover and other phenomena;
  - Development of a non-destructive method to measure the stress in continuous welded rail, wheels and bearings;

- Ways and means to prolong the serviceable life of a wood track tie;

- Ways and means to shorten the time period for the development and testing of new or modified products for railway use.

## 4. ABSTRACTS OF TECHNICAL PAPERS

### Session #1 - Motive Power

**Railway Electrification.** C.A. Versailles, Senior Development Officer, Transportation Development Centre, Montreal, Que.

TDC's program of research and development in rail electrification has been oriented towards preparing Canada for possible future electrification of certain sectors of the country's rail system. To that end, TDC has supported research in the following areas: establishing the technical and economic characteristics of electrification; developing guidelines for electrification including those needed for signalling and communications; evaluating alternative electric and hybrid locomotive designs; and, identifying the system requirements and the related costs of specific electrification projects. A brief description of the work done or still in progress in each of these areas is given.

**DSL Fuelsaving Device.** G. Levesque, Project Engineer, DSL Dynamic Sciences Limited, Montreal, Que.

A new concept to greatly reduce the wasting of fuel due to idling of locomotives and to the excess of power in a train consist has been fully implemented on five SD40-2 locomotives. The automatic start/stop controller suitable for North American locomotives has been designed paying attention to safety, reliability, cost, ease of installation, operation and maintenance.

To achieve these objectives, full solid-state and micro-processor techniques were used, modern electro-mechanical devices were designed, special structured software techniques were used and practical railway locomotive experience was applied throughout the project.

Savings in the order of 55,000 litres per locomotive, per year, have been calculated from the results obtained during the testing of the prototype system. Five pre-production systems have been installed for larger scale testing.

**A Facility for Medium Speed Diesel Engine Research and Development.** Malcolm L. Payne, Engine Research and Development, Bombardier Rail and Diesel Products Division, Montreal, Que.

This report is an overview of the Bombardier Single Cylinder Research Engine (BSCRE) programme and its evolution to a full-capability research facility for medium speed diesel engines suitable for locomotives, ships and generators.

The program, which started in 1982, has progressed to the final stages of Phase III which covers the calibration and qualification of the 1-251 and 1-B2400 BSCRE versions.

A description of the engines and test cells is given. Also some of the R&D capabilities of the facility, including the yet to be completed fuels and lube analysis lab and the turbocharger development test cell, are highlighted in the paper.

**Microprocessor Control of AC-DC-AC Locomotives.** M.J. Nixon, Vice President, Synitek Inc., Pointe-Claire, Que.

With the inclusion of MICAS computers in the program to retrofit BBC three phase AC traction on a CP locomotive, a project was developed to optimize their use. The project involved the development of a systems laboratory facility and, in conjuntion with the University of Toronto, a real time interactive simulation and test facility, RIST. The project then concentrated on the development of wheelslip control software as well as engine control, protection, optimization and data logging concepts. In addition to the work, spin-off benefits came in the form of definitions for future hardware development.

**Train Data Recording System.** G.F. Guevara, Senior Engineer, and R.J. Clark, Asst. Vice President, Digital Products & Technology, MPB Technologies Inc., Dorval, Que.

The purpose of the development of the Train Data Recording System (TDRS) for CP Rail and the Transportation Development Centre is discussed, together with the system software/hardware facilities which are now available. Reference is made to new features currently under study and a modular approach proposed to meet future railway locomotive data communication requirements.

Existing features described include the monitoring of eighteen On/Off events plus eight analogue events, computation of acceleration/deceleration and length of train, display of all twenty-six parameters either digitally by means of a standard printer or graphically on a high resolution colour monitor. As well, the TDRS includes communications software to permit all or selected data to be communicated serially, for example, over existing train radio channels between a locomotive and a central dispatch centre. New features under investigation include the handling of messages between the dispatcher and the train, vigilance control, signal verification, cab display and keyset and the status of the end-of-train unit.

**Evaluation of Event Recorders.** D.W. Dibble, Senior Development Officer, Transportation Development Centre, Montreal, Que.

This paper describes an evaluation program of two commercially available event recorders, the Pulse Model 48H8-C-10 and the Hasler-Teloc-2000 DR undertaken by the Transportation Development Centre (TDC), at the request of the Railway Transport Committee (RTC). The program was carried out in conjunction with the RTC, Canadian National and CP Rail. The objective of the project was to determine the operational suitability for accident investigation of locomotive event recorders that were potential candidates for installation on Canadian locomotives.

Both recorders that were evaluated recorded at least the following eight required events: time, speed, throttle level, brake pipe pressure, independent brake cylinder pressure, locomotive initiated emergency, whistle and distance.

For the evaluation, 10 Pulse recorders were installed on CN locomotives and 8 Hasler recorders were installed on CP Rail locomotives. During the evaluation period, there were no operational or maintenance problems associated with the recorders. Accident simulation tests were performed that involved recording, in parallel, the identical signals that the event recorders were recording. For each test, the data from the different sources were compared and the event recorder data were generally found to be extremely accurate. The general test results for both recorder models indicated that the recorders could survive under the operating conditions encountered on a diesel locomotive and record and retain reliable data.

## Session #2 - Track and Infrastructure

**Rail Wear and Contact Fatigue Model Utilizing Lubrication and Grinding to Extend Rail Life.** J. Kalousek, National Research Council, Vancouver, BC.

Rail located in curves of heavy haul railway lines may experience four different modes of wear: gouging wear at the gauge face and oxidative wear on the rail's top surfaces in the case of unlubricated rail, and delamination and mild abrasive wear if the rail is lubricated. Lubrication, whilst effectively controlling the gouging wear, leads to the development of contact fatigue corrugations. Based on the analysis of contact fatigue crack initiation and propagation, a new method of grinding is proposed. It is shown that this method can prevent the development of contact fatigue corrugations and substantially increase rail life.

**Improved Austenitic Manganese Steel for Railway Applications.** W.B.F. Mackay and R.W. Smith, Department of Metallurgical Engineering, Queen's University, Kingston, Ont.

An improved austenitic manganese steel capable of giving longer life to such railroad components as frogs would be economically desirable. Work at Queen's over the last six years has been directed towards increasing the yield strength and wear resistance by minor alloy additions and variations in heat treatment. At the same time the capacity for work hardening and the excellent toughness of the original Hadfield's composition FE-13%Mn-1.2%C should not be drastically sacrificed. In addition, studies are continuing on weldability, response to explosive hardening and the screening of alloys by means of a specially designed impact-wear tester. It is intended that recently received funding from the Transportation Development Centre and CP Limited, will be utilized to study further variations in C content and small multi-alloy additions with their synergistic effect on mechanical properties which appear to have promise.

**Full-scale Wheel/Rail Test Facility.** H.G. Tucker, Associate Research Officer, National Research Council, Ottawa, Ont.

The design and build of a facility capable of testing a full-scale, standard gauge wheelset and associated brake rigging is being undertaken by the National Research Council (NRC) with partial funding by TDC. The facility is to be capable of extended duration wear tests (i.e. of a month or more duration) and the testing of wheelset components (brakes, wheels, bearings and axles) under controlled, yet realistic, environmental conditions. The facility will be unique in that it is to simulate, at full-scale, both the rail/wheel and brake/wheel interface while allowing for control of temperature and introduction of contaminants.

The facility will use two driven rollers to simulate rails and will consist of a double frame wherein the flexure-mounted inner frame can move relative to a stiff outer frame. Such flexure mounting allows for positioning of the wheelset relative to the rollers and for incorporation of load cells to measure the relevant force components at each roller. The wheelset will be positioned using ball screws and vertically loaded using hydraulic actuators.

The configuration represents an attempt to simulate, as accurately as possible, actual wheel/rail contact conditions without compromising mechanical simplicity or operating reliability.

The facility is to be located at the NRC Vehicle Dynamics Laboratory, Ottawa, with access to the recently commissioned NRC Environmental Chamber, and is to be available for use by the railway industry and for in-house research.

**Track Research Program - An Overview of Current Status.** S.T. Lamson, Manager, Track Research Program, Canadian Institute of Guided Ground Transport, Kingston, Ont.

The track research program centres on i) component improvement and ii) track system modelling. The focus of component improvement has been geotextile, subballast, tie and rail. The focus of track system modelling has been technical validity and ease of application.

Achievements in the first area include: a) a comprehensive manual on geotextile selection and application; b) a detailed guideline on track design with or without geotextile for a range of existing subballast materials; c) a better understanding of wood tie degradation that would lead to techniques for improving tie performance; d) an optimal rail profile which reduces existing rail corrugation and fatigue problems.

Achievements in the second area include: a) a track system model consisting of four modules - vehicle dynamics, rail life, tie life, surfacing and lining cycle; b) a data acquisition and analysis system which permits the recording of track dynamic and permanent settlement as well as track geometry error growth; c) a set of vehicle/track dynamic interaction computer simulation models which permit a wide range of dynamic track force analyses; d) a comprehensive analysis of track maintenance on an operating railroad.

**Reinforced Embankments.** J.R. Busbridge, Golder Associates, Mississauga, Ont.

The use of reinforcement, commonly consisting of geotextiles or geogrids, to stabilize embankments is discussed. There are three broad goups of applications; viz. fill slopes on good foundations, rehabilitation of natural slopes and the reinforcement of fill to compensate for weak foundations. Examples of each group are given and design methodologies noted. One unreinforced and two reinforced embankments near St. Albans Que., all instrumented, were constructed to failure. Data derived from this work are discussed.

**Ballast and Geotextile Research.** Gerald P. Raymond, Professor of Civil Engineering, Queen's University, Kingston, Ont.

Aggregate selection for ballast is discussed from the standpoints of how the aggregate weathers, how it resists load related degradation and how it contributes to track stability. Factors which influence the effectiveness of geotextiles installed to improve embankment stabilization and drainage are identified and discussed. The functions of subballast in improving railway track performance are reviewed and methods to ensure the desired improvement is achieved are described.

## Session #3 - Freight Cars

**Train Dynamics Simulation.** M.H. Kelley, Project Engineer, DSL Dynamic Sciences Limited, Montreal, Que.

This presentation describes the capabilities and applications of a tool that will provide railway and other organizations with a real-time research and simulation capability for longitudinal train action and control. This tool has been packaged in the form of a real-time train simulation software program. The simulation program provides the ability for the operator to determine dynamic longitudinal forces at couplers and the longitudinal acceleration of cars within the train. It models air brakes, locomotive systems, and effects due to rolling and curve resistances and grade. It also provides for non-real-time operation (slower than real-time) which allows for more detailed generation of results. The program has been configured in a form which allows for a broad range of flexibility, including user interaction using friendly keys, batch or repeatable inputs, initiation of undesired conditions and malfunctions, and the ability to choose alternate track conditions during the run. The software program is in its testing phase and, in the near future, will be installed on NRC facilities so special research studies may be conducted.

**Train Resistance Field Tests: Interim Results.** G.W. English, Senior Research Engineer, and J.D. Young, Research Engineer, Canadian Institute of Guided Ground Transport, Kingston, Ont.

CIGGT is currently carrying out a project to obtain and analyze detailed train resistance data from revenue train operations. The project is being funded by Transportation Development Centre of Transport Canada. CN Rail has provided cooperation and assistance in the collection of the data. NRC has cooperated in providing anemometer calibration and instrumentation.

Eight runs of Toronto-Montreal intermodal trains were recorded on analogue tape. These data were then digitized for analysis on a personal computer. The data recorded included speed, drawbar force, wind speed and direction, throttle position, train line brake pressure, locomotive independent brake pressure and track gradient. Sections were identified for coast-down and acceleration tests.

Two types of intermodal cars were tested:

- an older single platform car
- a low profile articulated "5-pack" car.

The data collected for the eight runs will allow an examination of the effects of bearings, track quality, trailer spacings and car configurations on train resistance. The data will be used in an attempt to validate theoretical, laboratory and wind tunnel investigations of train resistance.

The data collected have been digitized and reduced, and statistical analysis initiated. Problems were apparent with the gradient data for the test segments. Currently, work on the project involves obtaining new gradient data for the test sections in order that the grade resistance portion of the train resistance can be factored out with confidence.

**Train Aerodynamics.** Kevin R. Cooper, Low Speed Aerodynamics Lab., National Research Council, Ottawa, Ont.

The intention of this paper is to quantify the aerodynamic behaviour of trains in the open and in tunnels. The main emphasis is on energy conservation through reduced aerodynamic drag design and on safety through an examination of overturning due to wind action. The energy question, particularly, is decided by small differences between large numbers and so demands accurate test results and a realistic analysis using the test data for meaningful economic predictions. The application of wind tunnel measurements is discussed with these ultimate needs in mind.

**Frame Bracing for 3-Piece Cast Steel Freight Trucks: The Economical "Radial" Technology.** J.W. Horwat, Project Engineer, AII Transportation Technology Limited, Kingston, Ont.

The Frame-Braced Freight Truck program was begun in 1980 as an integral research program and expanded to a research, design, build and test program in 1981 under the sponsorship of the Transportation Development Centre and Ontario Ministries of Transportation and Communication and Northern Affairs. The program resulted in a simple design of a new truck or retrofit parts which when added to a conventional three-piece freight truck improves the dynamic stability and curving ability of the truck, increasing operating speed capability and reducing wheel, especially flange, wear. Research results and test results are presented graphically showing their relationship. In addition, the market and the sales to date are discussed, as is also the favourable cost/benefit analysis.

**Radial Axle Freight Car Truck Test.** V. Khatchadourian, Senior Research Engineer, CP Rail, Montreal, Que.

The Department of Research and Development of CP Rail conducted in-service evaluation tests of Barber Scheffel and DR-2 self steering trucks. The Barber Scheffel trucks introduced into service in January, 1982 have accumulated close to 400,000 miles of revenue service operation. The DR-2 trucks have accumulated 150,000 miles of revenue service operation.

This paper discusses the results of wheel wear measurements carried out on the Barber Scheffel and the DR-2 self steering trucks. The results of a radial truck tear-down inspection are presented and discussed. A brief description of laboratory fatigue testing with DR-2 steering arms is also presented.

As part of this test program, other retrofit freight car trucks were also evaluated in 1984 and 1985, for high speed stability and curving performance. The UTDC frame-braced 100-ton truck and the 70-ton rigidized elasto cushion trucks were tested. The results are presented.

In 1986 CP Rail introduced the first trainset of coal cars equipped with Barber Radial and DR-2 trucks into revenue service. A brief description of the proposed 1986 test program is presented.

**Tank-Car Thermal Model.** A. Michael Birk, Senior Engineer, W.R. Davis Engineering Limited, Ottawa, Ont.

A computer model has been developed which can simulate the response of a tank-car, and its lading, to external fire impingement. This model has been developed to study the effectiveness of a variety of thermal protection systems for protecting against the risk of thermally induced tank rupture.

The computer model can simulate a rail tank-car, or any other long cylindrical tank, filled with a number of light petroleum products, such as propane and propylene. The model can simulate both an engulfing type fire or a torch type fire. Tank roll and pitch can be accounted for.

The model can predict tank internal pressure, tank wall temperature distributions, mean lading temperatures, relief valve flow rates, liquid level, tank wall stress conditions, and tank failure, all as functions of time from fire ignition. The computer model has been validated using available experimental data from full and fifth-scale fire tests conducted on tank-cars filled with propane.

Thermal protection systems that can presently be simulated include: thermal insulation, thermal radiation shielding, internal thermal protection, fusible plug pressure relief devices, and pressure relief valves. The above systems can be modelled separately, or in any combination.

Example validation results are presented for unprotected tanks exposed to engulfing fire and a torch type fire. Simulation results are presented for tanks with varying insulation thicknesses.

**High Productivity Train.** D.N. Ferrance, Project Engineer, Transportation Technology Limited, Kingston, Ont.

The Association of American Railroads (AAR) initiated a major program in 1984 to promote the development of a new generation of trains [high productivity integral trains (HPIT)] to transport bulk and intermodal commodities. The Transportation Development Centre recognized the need for such railroad industry technological advances and supported the first phase of a program proposed by Transportation Technology Limited to develop new train system technology in response to the AAR challenge. Two distinct HPIT conceptual designs resulted from the work - a near term design and an advanced design.

The near term design (not discussed in this paper), has container and trailer variants that offer train operation savings of approximately 20% and that can be introduced into revenue service within two years. The cars are short, with two or three axles, having drawbars with slackless couplers. Each car supports one-half of two containers.

This paper deals with the advanced design. It offers origin to destination cost savings of 50% for intermodal freight, operational flexibility, and will require a four-year development and test program. The train arrangement consists primarily of monocoque car bodies to accomodate containers, distributed propulsion, a command module to control train operation and single axle radial trucks. This design is revolutionary, but the technology is largely available or near production status in other industrial applications.

## Session #4 - Signalling and Communications

**End of Train Monitoring.** Dr. R.J. Pomeroy, Vice President, DSL Dynamic Sciences Ltd., Vancouver, B.C.

Economic pressure in the railroad industry has resulted in a search for ways to reduce operating costs. As a direct result, technology has been developed in the form of rear-of-train telemetry equipment. A Sense and Transmit Unit mounted on the trailing coupler of the last car conveys brake pipe air pressure and motion status to a Receiver Display Unit in the locomotive cab. A manually-initiated odometer in the locomotive provides a measurement of distance travelled past a point. Equipment embodying the capabilities outlined above has been in operational service in the United States since July, 1984, and has been successfully tested and demonstrated in Canada. A recent enhancement, developed for the Canadian market, incorporates the capability to apply emergency braking from the rear of the train, initiated in the locomotive cab.

**Light Emitting Diode Signal Technology.** J.A. Lougheed, Director of Research, W.R. Davis Engineering Ltd., Ottawa, Ont.

The paper begins with an explanation of the fundamental optical and visual properties of long-range wayside signals, and how TDC has been supporting technology to improve reliability and safety. The existing signals utilize incandescent lamps as the light source, interposing red, yellow or green filters by use of an electrically driven mechanism. The light emitting diode (LED) project set out to eliminate both lamp burnout and moving parts, through the use of high brightness LEDs of each colour, electronically switched.

After reviewing the current state of LED technology, advantages and disadvantages compared to incandescent lamps are discussed, and the research approach taken is explained. It is emphasized that the optical treatment of LEDs is different than for traditional point sources if maximum output is needed, and two approaches are shown. Complexities introduced by the qualitative nature of existing specifications are discussed, along with the method used for quantifying the results of visibility tests of the prototypes.

Optical characteristics of the prototype LED inserts for retrofitting existing signals delivered to TDC at the end of the project are discussed. They provide 800 meter range in bright sunlight, exceeding the minimum requirement but falling short of complete equivalence. Far greater range is attainable with red LEDs, but yellow and green lag because the individual devices are less bright. Also, the best green currently available is deficient in blue according to specifications, although tests by individuals with normal colour vision were satisfactory.

**Container Terminal Simulation Model.** P.R. Rossi, M.A. MacIsaac, E.D. Brown, I.A. Grunwell, Department of Operational Research, Canadian National Railways, Montreal, Que.

The Container Terminal Simulation is a computer simulation of the major operations in an inland container terminal: inbound train arrivals and unloading, outbound train departures and loading, storage of containers arriving by train or by truck, customer pick-up of containers. The model consists of a batch simulation and a graphical postprocessor. The simulation evaluates plant designs, equipment trade-offs and yard operating policies. The model was used in the design of the Montreal container facility and is currently being used to assess the effect that changes in traffic levels would have on yard operations for the container facilities in both Toronto and Montreal.

**BC Rail's Advanced Train Control System.** B.E. Mrazek, P.Eng., Telecommunications Consultant, Vancouver, B.C.

The paper commences with a brief outline of BC Rail's endeavours, during the early 1970's and the period from 1979 to 1984, to implement the Location, Identification and Control (LIC) System. The joint Railway Association of Canada (RAC) and Association of American Railroads (AAR) Automatic Train Control Systems (ATCS) is described followed by a description of BC Rail's recent efforts to implement an ATCS on their North Vancouver-Squamish subdivision, utilizing the components of LIC which are ATCS compatible.

An overview of the ATCS system adopted by BC Rail is provided. All major components of the system are identified and their functions described. The components described include:

- host computer
- dispatcher man-machine interface
- network manager
- cluster controller
- radio site equipment
- engine equipment
- caboose equipment
- wayside equipment
- MOW equipment

Detailed descriptions are given of:

- the data communications protocol explaining how the problems encountered in the past have been overcome

- the engine equipment, particularly the manner in which the main processor interfaces with the processors associated with the various peripheral devices
- the graphics used with the cab display unit.

**Advanced Train Control Systems.** E.W. Baynton, General Supt. Transportation Operation and Development, CP Rail, Montreal, Que.

This paper describes the progress made to date with the Advanced Train Control Systems project.

Overall objectives with respect to train operations have been established; viz. safety, economy and reliability. Operating requirements, defined by a working group representing five Canadian and two U.S. railroads, have been published. That working group, augmented by representatives of two additional major U.S. railroads now serves as the project steering committee. Other railroads and the supply industry have been kept abreast of progress through two large public meetings. Development of the systems engineering is being advanced.

# SOMMAIRE

## 1. INTRODUCTION

Le séminaire sur la R&D en matière de transport ferroviaire de marchandises a eu lieu au Centre de conférences du complexe Guy-Favreau à Montréal, les 12 et 13 juin 1986, sous l'égide du Centre de développement des transports (CDT) de Transports Canada, de concert avec le Conseil consultatif du transport ferroviaire relevant de ce ministère et l'Association des chemins de fer du Canada.

Le Centre de développement des transports, Transports Canada, a toujours fait une large place au transport ferroviaire de marchandises dans son programme de R&D. À preuve, le programme élargi de R&D étalé sur cinq ans, de 1981 à 1986, pour lequel les dépenses engagées ont dépassé les 14 millions, y compris les contributions des sociétés de chemin de fer du Canada et leurs fournisseurs.

Compte tenu de ce programme élargi, le CDT a apporté, depuis sa fondation en 1970, son concours financier à quelque 275 projets de R&D concernant ce type de transport, desquels 240 environ ont été menés à terme, chacun d'eux ayant fait l'objet d'un compte rendu complet destiné tant aux chercheurs qu'aux autres intéressés: bibliothèques, particuliers, par exemple.

Le séminaire s'était donné pour objectif principal d'apporter la riche information contenue dans tous ces comptes rendus à l'attention d'un auditoire beaucoup plus vaste, dans les milieux scientifiques et le personnel technique des sociétés de chemin de fer du Canada, de manière à en valoriser les retombées auprès de cet auditoire privilégié et, indirectement, à en faire profiter le Canada dans son ensemble. Un deuxième objectif était visé: connaître l'opinion des intéressés sur l'utilité de la recherche coopérative qui a été la manière de procéder en ce qui concerne ce programme, et recueillir des suggestions sur la nature des travaux à entreprendre à l'avenir.

## 2. COMPTE RENDU DU JEUDI 12 JUIN

Les délégués ont été accueillis par M. P.J. Detmold, président du Comité consultatif du transport ferroviaire (CCTF) et président du séminaire, qui, dans une brève allocution, a parlé avec enthousiasme de la recherche coopérative, seule manière d'après lui d'assurer que les produits résultant de la recherche soient adaptables à l'ensemble du réseau ferroviaire nord-américain. On sait que, pour donner de bons services, tout produit doit être standardisé et il n'y a pas de meilleure garantie de cela que la participation et la coopération de toutes les parties prenantes. D'où la nécessité de l'action coopérative. L'orateur a poursuivi en soulignant l'importance de la prospection dans le but de reconnaître les nécessités de demain et de tracer la voie vers leur réalisation en temps utile. Dans ce processus de planification, a-t-il ajouté, place devra être faite aux fournisseurs, sans la consultation desquels les critères performances et délais ne sauraient être satisfaits.

Ayant terminé, il a présenté M. N.E. Rudback, directeur exécutif du Centre de développement des transports de Transports Canada, qui, au nom de ce ministère, a souhaité la bienvenue aux délégués. M. Rudback a fait observer que le programme de R&D en transport ferroviaire de marchandises entrepris par le CDT a surtout visé jusqu'ici un accroissement de la productivité et la stimulation de la recherche appliquée, mais que la sécurité s'est trouvée et se trouve toujours bien servie par ces travaux. Par ailleurs, a-t-il ajouté, les coupures budgétaires décidées ne manqueront pas d'influer, du moins à court terme, sur l'ampleur du programme, imposant du même coup une justification encore plus serrée de chaque projet envisagé. Même la nature du programme change, a-t-il déclaré, la recherche aspirant maintenant à un accroissement de plus en plus prononcé de la sécurité et n'obtenant qu'accessoirement des gains de productivité.

Puis, M. Rudback a passé la parole à M. W.S.C. McLaren, chef de la division Technologie courante du CDT et agent responsable de la mise en oeuvre du programme de R&D en transport ferroviaire de marchandises. Dans son tour d'horizon de ce programme, M. McLaren a révélé que le séminaire avait été organisé à la demande du directeur général de la R&D à Transports Canada et que les travaux devant être passés en revue appartenaient à ce programme, à une exception près, c'est-à-dire l'étude concernant les systèmes avancés de commande des trains (SACT). Il a souligné la nature coopérative de ce programme en faisant remarquer que:

i) six sociétés de chemin de fer ont participé activement au programme et à son financement: CN, CP, BC Rail, Québec North Shore & Labrador, Ontario Northland Railway et enfin la compagnie de chemin de fer Cartier;

ii) les travaux ont été partagés entre 35 contractants, quatre d'entre eux ayant au surplus concouru financièrement;

iii) les fonds fédéraux destinés à ce programme ont été versés par l'entremise du CDT, à la fois gestionnaire et parrain du programme; que d'autres fonds ont été versés au titre du programme énergétique national et du programme de propositions spontanées et, enfin, que l'apport du Conseil national de recherches a été considérable, en actions de recherche sinon en argent;

iv) au niveau international, la coopération s'est réalisée aux termes du protocole d'entente avec le ministère américain des Transports (accord Jamieson/Volpe);

v) cette coopération entre les sociétés ferroviaires nord-américaines avait été coordonnée par le comité directeur sur la dynamique du contact roue-rail, et que les services de recherche et d'essai de l'Association of American Railroads ont joué le rôle de pivot dans les échanges d'information entre les membres.

M. McLaren a poursuivi en disant que le programme régulier du CDT en matière de R&D en transport ferroviaire de marchandises avait connu une forte relance par la mise en oeuvre, en 1981, du programme élargi au titre duquel quelque 9 millions de dollars devaient s'ajouter au budget correspondant du CDT au cours de la période de cinq années se terminant en 1986, accroissement appréciable par rapport au million que le CDT consacrait à ce secteur annuellement, à même son budget propre. Il a souligné que, étant donné la courte durée du séminaire, les participants n'auraient le temps d'étudier que quelques-uns des 80 projets ou plus appartenant au programme élargi, mais, a-t-il aussitôt précisé, que toute l'information pertinente concernant l'ensemble de ces projets est contenue dans le dossier remis aux délégués au moment de leur inscription.

Après avoir passé en revue les activités prévues pour la journée du 12 juin, M. McLaren a rappelé que le programme du lendemain prévoyait une assemblée publique du Comité consultatif du transport ferroviaire, lequel promettait d'offrir d'intéressants aperçus ainsi qu'un fructueux échange d'idées sur tout le programme de R&D.

Le reste de cette première journée a été consacré à la tenue de quatre ateliers, deux le matin et deux l'après-midi, placés sous les thèmes suivants: matériel de traction, matériel marchandises, infrastructure et voies ferrées et, enfin, installations de sécurité. Ces ateliers, qui correspondent aux quatre principaux axes du programme de R&D, ont été présidés par un membre du CCTF directement concerné. Chacun des 25 mémoires soumis portait sur l'une ou l'autre des principales actions de R&D lancées; les résumés de ces mémoires sont présentés en section 4.

## 3. COMPTE RENDU DU VENDREDI 13 JUIN

La dernière séance du séminaire s'est tenue au matin du deuxième jour, prenant la forme d'une assemblée publique du CCTF, sous la houlette de son président en exercice, M. Detmold. Elle a commencé par la revue des mémoires présentés la veille, faite tour à tour par les membres du CCTF directement concernés; ensuite, un débat a suivi sur les trois questions soulevées par le président concernant l'ensemble du programme de R&D.

La séance a été ajournée un peu après le coup de midi.

Voici, condensées, les réflexions des participants au débat à l'égard des questions soulevées:

### La recherche coopérative est-elle utile?

Le programme de R&D en transport ferroviaire de marchandises est, dans son ensemble, le fruit de la coopération entre les sociétés de chemin de fer (s'exprimant par la bouche du CCTF) et les gouvernements. À un autre niveau, certaines actions ont été lancées conjointement par des sociétés rivales et ont intéressé des fournisseurs concurrents qui ont cependant travaillé de concert en vue de résoudre des problèmes qu'ils ont en commun, sous l'impulsion de Transports Canada jouant le rôle de catalyseur, en plus d'être le principal bailleur de fonds. Généralement parlant, les objectifs techniques fixés aux projets de recherche considérés ayant été généralement atteints, on peut affirmer que la recherche coopérative a fait ses preuves. Par contre, on n'est souvent pas en mesure de dire que les résultats obtenus justifient les coûts.

Cela a mené à la question suivante: si les utilisateurs en bout de ligne ne voyaient pas suffisamment d'avantages à financer une recherche donnée, qu'est-ce qui les a poussés à s'y lancer? Autrement dit, sans la participation financière des gouvernements, jusqu'où serait-on allé?

Le cas du Système avancé de commande des trains (SACT) constitue, du moins jusqu'ici, une autre forme de recherche coopérative: partage des coûts et des avantages entre les parties intervenantes, chacune étant persuadée que ceux-ci justifieront ceux-là. On a fait remarquer, cependant, que la recherche sur le SACT tirait son origine de travaux antérieurs financés par Transports Canada, sans lesquels cette recherche n'aurait tout simplement pas eu lieu, du moins maintenant. Dans ce cas, le coût de la recherche antérieure se trouve-t-il justifié?

On sait que, dans le passé, des actions de recherche, financées par le secteur public ou le secteur privé, ou les deux ensemble, ont été lancées sans le bénéfice d'une étude suffisamment poussée du rapport coût-avantages correspondant. D'un autre côté, il n'est pas dit qu'une action étudiée à fond sous ce rapport doive être automatiquement écartée si le rapport avantages-coût dégagé n'est pas suffisamment favorable. En effet, il n'est pas toujours possible de prévoir tous les avantages futurs d'une recherche, et encore moins de les chiffrer avec précision. À titre d'exemple, le laser dont la mise au point n'a débouché sur des applications commercialement avantageuses que de nombreuses années après les premiers travaux de recherche. La décision d'entreprendre ou de ne pas entreprendre une action de R&D sur le transport ferroviaire de marchandises qui semble avantageuse, mais à l'égard de laquelle on ne peut dégager un rapport avantages-coût favorable, une telle décision, donc, ne saurait être prise que par des gestionnaires d'expérience après consultation avec toutes les parties intéressées: exploitants, fournisseurs, secteur public - comme il se doit. Par ailleurs, même si les fonds nécessaires sont disponibles, il y a lieu de se rappeler que d'autres projets en concurrence pour les mêmes ressources humaines, techniques ou autres peuvent être plus pressants ou plus utiles.

**La coopération devrait-elle exister entre les fournisseurs des sociétés de chemin de fer?**

Pour ces fournisseurs, a-t-on fait observer, la conjoncture au Canada diffère de celle d'Europe et des États-Unis. En Europe, les sociétés ferroviaires nationales collaborent étroitement avec les fournisseurs dans la mise au point de produits et de systèmes qu'elles entendent mettre à des usages spécifiques. Aux États-Unis, le système de la libre entreprise fonctionne bien parce qu'il y existe de très grosses entreprises qui consentent à faire de gros investissements dans la R&D étant assurées, d'une part, de vastes débouchés et, d'autre part, d'un rendement financier suffisant. Au Canada, les entreprises de fabrication d'équipements ferroviaires, comme leurs débouchés, sont de plus petite envergure qu'aux États-Unis, alors que les coûts de développement des produits y sont aussi élevés. Cette réalité fait qu'aucun fabricant canadien ne peut se permettre de lancer, seul, un ambitieux programme de R&D et que, sans le concours financier de l'État, le Canada se trouverait privé de développements intéressants, tels le système de surveillance en queue de train et le simulateur de pilotage des trains. Or ces développements ont maintenant des retombées qui avantagent non seulement ceux qui les ont conçus, mais aussi les sociétés canadiennes de chemin de fer et, par là, l'économie du pays.

**Quels projets de R&D devrait-on entreprendre?**

- Étude des forces longitudinales agissant sur les éléments d'un train, utilisant le modèle élaboré par DSL Dynamic Sciences Ltd. dans le cadre du programme de R&D en transport ferroviaire de marchandises. Cette étude devrait bâtir sur le travail antérieur fait dans ce domaine, notamment par John Punwani de l'AAR.

- Amélioration des bogies du matériel marchandises, y compris les organes de roulement et de freinage. Cette étude doit tenir compte du coût de premier investissement, du coût d'entretien et aussi du problème posé par la standardisation des éléments et organes, vu le très grand nombre de bogies "classiques" en circulation sur les réseaux ferroviaires nord-américains.

- Dans le domaine de la transmission des données:

  . Caractérisation par voie statistique des liaisons hertziennes utilisées pour la transmission de données entre le train et les installations au sol, d'un bout à l'autre du train, pour la télécommande des aiguillages ou pour le SACT, le but de cette recherche étant de déterminer le type de modem à utiliser dans chaque cas et de définir des mécanismes pour la détection et la correction des erreurs.

- Dans le domaine de la sécurité:

  . Moyens à mettre en oeuvre pour réduire le nombre d'accidents aux passages à niveau;

  . Techniques de simulation pour la détermination des forces agissant sur les rails et aboutissant au surécartement de ceux-ci ou à des phénomènes aussi dangereux;

  . Mise au point d'une méthode de contrôle non destructif pour mesurer les contraintes dans les longs rails soudés, les organes de roulement, les paliers;

- Moyens à prendre pour prolonger la durée de vie des traverses en bois;

- Moyens permettant de réduire le temps de mise au point et d'essai d'un équipement neuf ou modifié à usages ferroviaires.

## 4. RÉSUMÉ DES MÉMOIRES

### Atelier 1 - Matériel de traction

**Électrification des voies ferrées.** C.A. Versailles, Agent principal de développement, Centre de développement des transports, Montréal, Qué.

Le programme de R&D du CDT dans ce domaine a cherché à préparer l'électrification éventuelle de certaines lignes du réseau ferroviaire du Canada. Pour cela, le CDT a financé la recherche dans les secteurs suivants: aspect technico-économique de l'électrification; normes d'électrification prenant notamment en compte les impératifs de non parasitage des installations de sécurité; évaluation comparée des locomotives électriques et hybrides; détermination des exigences et sujétions en matière d'électrification et étude des coûts y afférents pour un projet donné. Une brève description des travaux terminés ou en cours d'achèvement dans chacun de ces secteurs est donnée.

**Économie de carburant en traction ferroviaire.** G. Lévesque, ingénieur-projeteur, DSL Dynamic Sciences Ltd., Montréal, Qué.

Une nouvelle façon de réduire considérablement la consommation a été mise en oeuvre sur cinq locomotives SD40-2. Il s'agit de réduire les périodes de ralenti et les surpuissances de traction par rapport aux besoins. Le système d'arrêt et de relance automatiques conçu à cette fin, en plus d'être adaptable aux locomotives utilisées par les chemins de fer nord-américains, satisfait aux conditions de sécurité, fiabilité, coûts et facilité de pose, mise en oeuvre et entretien.

La réalisation de ce système a fait appel à la micro-électronique et à l'électronique de puissance, à des dispositifs électro-mécaniques modernes, et à des logiciels spécialement structurés, le tout fondé sur des connaissances solides du fonctionnement des locomotives diesel.

Les essais du prototype de ce système ont permis d'extrapoler des économies de 55 000 litres de carburant par locomotive, par an. Cinq locomotives ont été équipées d'un système pré-série aux fins d'essais à plus grande échelle.

**Recherche sur les moteurs diesel semi-rapides.** Malcolm L. Payne, Recherche et développement, moteurs thermiques, Bombardier Inc., Montréal, Qué.

Ce mémoire passe en revue le programme de R&D en laboratoire lancé par Bombardier sur des moteurs monocylindres, et qui a débouché sur une installation complète pour la caractérisation des moteurs diesel semi-rapides destinés à la traction ferroviaire, la propulsion marine ou la production d'électricité.

Lancé en 1982, ce programme en est maintenant à la dernière étape de la phase III, c'est-à-dire l'étalonnage et la qualification des versions monocylindres des moteurs 251 et B2400.

Le mémoire décrit les moteurs, les bancs d'essai et certains laboratoires, comme celui consacré à l'analyse des carburants et des lubrifiants et qui n'est pas encore terminé, et, enfin, un banc d'essai et de mise au point de turbocompresseurs.

**Informatisation des circuits de commande.** M.J. Nixon, vice-président, Synitk Inc., Pointe-Claire, Qué.

Un des aspects de la modernisation des moteurs de traction triphasés, alternatif-continu-alternatif, équipant des locomotives du CP, étant l'utilisation d'un ordinateur MICAS, un programme a été mis au point en vue d'optimiser l'électronique de commande. Il a fallu pour cela réaliser un banc d'essai et, de concert avec l'Université de Toronto, construire un deuxième banc sur lequel on pourrait simuler en temps réel le fonctionnement d'un moteur. Ensuite, la recherche a porté sur les systèmes automatiques anti-patinage et de réglage de la marche, les protections, l'optimisation proprement dite et, enfin, le système d'enregistrement des paramètres de marche. D'autres résultats ont été obtenus, notamment le descriptif de certains matériels à mettre au point.

**Enregistrement des paramètres de marche.** G.F. Guevara, ingénieur principal, et R.J. Clark, vice-président adjoint, technologie et matériels numériques, MPB Technologies Inc., Dorval, Qué.

Ce mémoire traite de la mise au point d'un système d'enregistrement automatique des paramètres de marche d'un train, réalisé à la demande de CP Rail et du Centre de développement des transports, ainsi que du matériel et logiciel informatiques qui l'accompagnent. Il fait état des nouvelles fonctions encore à l'étude et de l'approche modulaire adoptée afin de répondre avec souplesse aux besoins des sociétés de chemin de fer.

Les fonctions existantes concernent le suivi de 18 événements en numérique et 8 en analogique; le calcul des accélérations-ralentissements et de la longueur du train; l'affichage de ces 26 paramètres en numérique à l'aide d'une imprimante standard, ou en infographique sur un écran couleur haute résolution; la transmission de toutes ou de certaines données en série, notamment grâce aux liaisons hertziennes existant entre le train et le centre de contrôle. Les nouvelles fonctions encore à l'étude sont: le traitement des messages entre le train et le centre de contrôle, la vigilance, la vérification des signaux, l'affichage en cabine par touches et l'état du dispositif de surveillance en queue de train.

**Évaluation des systèmes TDRS.** D.W. Dibble, Agent principal de développement, Centre de développement des transports, Montréal, Qué.

Ce mémoire décrit le programme d'évaluation de deux enregistreurs-marqueurs d'événements sur le marché, à savoir le Pulse modèle 48H8-C-10 et le Hasler-Teloc 2000 DR, lancé par le CDT à la demande du Comité des transports par chemin de fer et auquel ont participé ce même Comité, le CN et le CP. Ce programme visait à établir l'utilité de ces appareils dans la détermination des causes d'un accident par des essais de performances et l'analyse des caractéristiques de fiabilité et de maintenabilité des appareils les plus prometteurs.

L'évaluation des deux modèles retenus a porté sur la qualité d'enregistrement d'au moins huit paramètres, soit: temps écoulé, vitesse, régime de marche, pression dans la conduite de freinage, pression dans le cylindre de frein, freinages d'urgence commandés à partir de la locomotive, coups d'avertisseur et distance.

Le CN a évalué le modèle Pulse équipant dix de ses locomotives et le CP, le modèle Hasler sur huit des siennes. Aucun ennui de marche ou d'entretien n'a été signalé. Il a été procédé à des simulations d'accident durant lesquelles les mêmes signaux ont été enregistrés parallèlement par d'autres appareils. La comparaison des données provenant de ces deux sources d'information a montré la grande précision des appareils enregistreurs considérés. Les essais ont révélé, en outre, que ces appareils supportent bien les dures conditions de service et qu'ils sont aptes à enregistrer fidèlement et à conserver les données.

## Atelier 2 - Infrastructure et voies ferrées

**Représentation de l'usure et de la fatigue des rails et prolongation de leur durée de vie par le graissage et le meulage.** J. Kalousek, Conseil national de recherches, Vancouver, C.-B.

Les rails d'une voie ferrée en courbe sur laquelle circule un trafic lourd peuvent connaître jusqu'à quatre modes d'usure. L'usure adhésive sévère de la face intérieure du rail et l'usure par oxydation des surfaces de roulement en glissement sec, d'une part, et délaminages accompagnés d'usure abrasive douce en glissement lubrifié, d'autre part. Si elle enraye efficacement l'usure adhésive, la lubrification provoque toutefois l'usure ondulaire par fatigue. À partir d'une analyse des causes d'apparition et de propagation des fissures dues à la fatigue de contact, le mémoire propose une nouvelle méthode de meulage des rails qui, a-t-on constaté, permet de prévenir l'usure ondulatoire et, de ce fait, de prolonger la durée utile des rails.

**Acier à rails austénitique au manganèse.** W.B.F. Mackay et R.W. Smith, département de génie métallurgique, Queen's University, Kingston, Ont.

Le mémoire traite de l'intérêt économique d'un acier à rails austénitique au manganèse de type amélioré, prolongeant la durée de vie des éléments de voie comme les coeurs de croisement. La recherche faite depuis six ans par cette université visait notamment à accroître la limite élastique et la résistance à l'usure des rails par l'addition d'éléments d'alliage en faibles quantités et par un traitement thermique approprié, sans compromettre sensiblement l'aptitude à l'écrouissage ainsi que la bonne ténacité de l'acier Hadfield dans lequel entrent 13 p. 100 de manganèse et 1,2 p. 100 de carbone. La recherche se poursuit sur la soudabilité de cet acier, son durcissement par voie explosive et une méthode de sélection des éléments d'alliage par des essais de la résistance aux chocs et à l'usure, à l'aide d'un appareil étudié exprès. Il est entendu que les fonds débloqués par le CDT et CP Ltée seront consacrés à approfondir l'influence que la teneur en carbone et l'addition de faibles quantités de certains alliages peuvent avoir sur les propriétés mécaniques de l'acier par un effet de synergie dont on attend beaucoup.

**Banc d'essai du système roue-rail.** H.G. Tucker, Agent de recherche associé, Conseil national de recherches, Ottawa, Ont.

Le CNR a entrepris l'étude et la réalisation d'un banc d'essai permettant d'étudier le comportement en vraie grandeur d'un essieu monté standard équipé de ses freins. Ce programme est financé en partie par le CDT. Conçu exprès pour des essais de longue durée, un mois ou plus, ce banc permet de vérifier la durabilité des éléments d'un essieu monté tels que freins, roues, paliers et essieux, dans des conditions climatiques contrôlées, représentatives de la réalité. Unique en son genre, il permet non seulement de simuler en vraie grandeur la géométrie du contact rail-roue et frein-roue, mais aussi d'introduire des agents de contamination et de varier les températures de fonctionnement.

Il comporte deux disques entraînés figurant les deux rails et un double bâti: celui de l'intérieur, pouvant se déplacer par rapport au bâti extérieur qui est rigide, autorise le positionnement de l'essieu monté par rapport aux disques et la mise en place de cellules dynamométriques mesurant les composantes des forces exercées sur chaque disque. Des vis à billes permettent le réglage transversal du bâti intérieur, et donc de l'essieu, lequel est chargé verticalement par des vérins hydrauliques.

Cet agencement vise à reproduire aussi fidèlement que possible le contact entre roues et rails, sans compromettre la simplicité mécanique et la fiabilité d'emploi.

Il sera logé dans le laboratoire de dynamique des véhicules du CNR à Ottawa, tout près de la chambre d'essais climatiques récemment mise en service. Il servira aux recherches lancées par le CNR ou par les chemins de fer intéressés.

**Recherche sur l'infrastructure des voies ferrées. - Tour d'horizon.** S.T. Lamson, directeur, programme de R&D sur les infrastructures, Canadian Institute of Guided Ground Transport, Kingston, Ont.

L'objectif de ce programme est double: 1) amélioration des infrastructures, 2) mise au point de modèles de prévision. Le premier est axé sur les géotextiles, les sous-couches du ballast, les traverses et les rails; le deuxième, sur la validation des modèles et la facilité d'emploi.

La première partie de la recherche a débouché sur: a) un manuel détaillé pour la sélection et la mise en oeuvre des géotextiles; b) un guide détaillé sur le calcul des infrastructures avec et sans géotextiles en fonction d'une gamme de granulats pour sous-couches; c) une meilleure connaissance des causes de la dégradation des traverses en bois, débouchant sur des techniques de protection améliorées; d) un profil optimal de roue permettant d'atténuer l'usure ondulatoire par fatigue.

La deuxième partie de la recherche a débouché sur: a) un modèle de prévision comportant quatre modules: dynamique des véhicules, durée de vie des rails, durée de vie des traverses et fréquence des nivellements et dressages de la voie; b) une chaîne de mesure pour l'enregistrement et l'analyse des données sur les tassements tant élastiques que permanents et sur l'amplification des défauts de voie; c) un ensemble de modèles de simulation par voie informatique de la géométrie du contact roue-rail permettant le calcul des forces en jeu dans des conditions dynamiques variables; d) un modèle de prévision des coûts d'entretien d'un réseau opérationnel.

**Remblais armés.** J.R. Busbridge, Golder Associates, Mississauga, Ont.

Ce mémoire traite des moyens utilisés pour accroître la stabilité des remplais, notamment les géotextiles et les géogrilles, dans trois grands groupes d'applications: remblais sur assises solides, réfection des talus naturels et confortement des remblais sur assises médiocres. Des exemples de chaque cas sont cités et les méthodes de calcul signalées. Trois remblais expérimentaux, dûment instrumentés, dont deux renforcés, ont été élevés jusqu'à rupture près de St-Alban (Québec). Les résultats de cette recherche sont explicités dans le mémoire.

**Recherche sur les ballasts et les géotextiles.** G.P. Raymond, professeur de génie civil, Queen's University, Kingston, Ont.

Ce mémoire traite de la sélection des granulats pour ballasts du point de vue de leur résistance à la dégradation due à l'environnement et aux charges ainsi que de la stabilité qu'ils confèrent aux voies ferrées; de l'efficacité des géotextiles destinés à accroître la stabilité et améliorer le drainage des remblais et des facteurs d'influence, et, enfin, des sous-couches: rôle joué dans l'amélioration de la géométrie des voies et méthodes susceptibles de donner les résultats attendus.

## Atelier 3 - Matériel marchandises

**Simulation de la dynamique des trains.** M.H. Kelley, ingénieur projeteur, DSL Dynamic Sciences Ltd., Montréal, Qué.

L'aptitude et l'utilité d'un outil de recherche permettant aux chemins de fer et à d'autres utilisateurs de simuler en temps réel le comportement dynamique longitudinal des trains sont commentés. Ce programme informatique permet à l'utilisateur de connaître l'amplitude des forces longitudinales sur les attelages et les accélérations correspondantes des wagons. En outre, il permet de prendre en compte l'action des freins à air comprimé, la traction exercée par les locomotives, la résistance de roulement et les efforts transversaux dans les voies en courbe ainsi que l'effet des rampes sur la marche des trains. Enfin, il permet la simulation en temps non réel (c'est-à-dire en temps ralenti) pour une analyse plus détaillée des phénomènes étudiés. Ce programme est doté d'une très grande souplesse d'emploi: il autorise le dialogue homme-machines à l'aide de touches faciles à comprendre, le traitement par lots, l'itération, l'introduction de facteurs indésirables ou d'incidents et le passage d'une voie à une autre en cours de simulation. Une fois les essais du logiciel achevés, celui-ci sera remis au CNR pour qu'on puisse y effectuer des recherches spécialisées.

**Résistance à la marche des trains - Expérimentations en ligne: rapport provisoire.** G.W. English, chercheur principal et J.D. Young, chercheur, Canadian Institute of Guided Ground Transport, Kingston, Ont.

Programme de recherche à bord de trains en service payant, financé par le CDT et exécuté par le CIGGT, avec la collaboration du CN qui a fourni le matériel de mesure et du CNR qui a monté et étalonné un anémomètre.

Huit parcours dans le corridor Toronto-Montréal ont été enregistrés sur bandes par voie analogique, à bord de trains intermodes, les données étant ensuite numérisées aux fins d'analyse sur un ordinateur personnel. Les paramètres enregistrés ont été les suivants: vitesse du train, effort au crochet, vitesse et direction du vent, régime de marche, pression dans la conduite de freinage, pression de freinage à la locomotive et profil en long de la voie. Les essais d'accélération et de marche sur erre ont eu lieu sur des tronçons bien délimités.

Les wagons utilisés étaient de deux types:

- le wagon plat classique
- le wagon articulé surbaissé "Five-pack"

Les données ainsi obtenues devaient permettre d'analyser l'influence des paliers, de la géométrie de voie, de l'espacement des semi-remorques et de la configuration des rames sur la résistance à la marche et servir à la validation des résultats des recherches théoriques, expérimentales et en soufflerie faites dans ce domaine.

Les données ont été numérisées et réduites, et leur analyse statistique a été amorcée. Celles concernant le profil en long des tronçons d'essais présentaient des lacunes, de sorte qu'il a fallu lancer une nouvelle série d'expérimentations en ligne pour obtenir des données fraîches à cet égard, données nécessaires pour cerner avec certitude la partie de la résistance globale attribuable aux rampes.

**Aérodynamique des trains.** Kevin R. Cooper, Aérodynamique des faibles vitesses, Conseil national de recherches, Ottawa, Ont.

Ce mémoire traite des véhicules sur rail dans l'optique de l'aérodynamicien et aborde la recherche faite pour chiffrer le comportement aérodynamique des trains tant à l'air libre que sous tunnels. L'accent est mis sur les économies d'énergie réalisables par la réduction de la traînée et sur la sécurité accrue découlant d'une réduction du couple de renversement dû au vent. Il faut observer que, surtout en matière d'économie d'énergie, il suffit souvent d'écarts minimes pour faire pencher la balance d'un côté ou de l'autre, les quantités en cause étant considérables. Aussi, pour arriver à des prévisions économiques valables, les données de départ doivent être aussi justes que leur analyse fiable. Ces objectifs doivent donc présider à toute application de la recherche faite en soufflerie.

**Bogie de wagon à liaison croisée des longerons: le bogie articulé.** J.W. Horwat, ingénieur de projet, Transportation Technology Limited, Kingston, Ont.

Lancée en 1980 à titre de recherche pure sur le bogie à liaison croisée des longerons, ce programme a été élargi en 1981 pour englober les aspects conception, réalisation et essais, sous les auspices du CDT ainsi que des ministères ontariens des Transports et des Communications, et des affaires du Nord. Il a débouché sur un nouveau bogie de conception simple et un mode de conversion des bogies classiques en bogies articulés, dont la stabilité de marche et l'inscription en courbe se trouvent grandement améliorées, la vitesse en service accrue et l'usure des roues, et surtout des boudins, réduite. Les résultats théoriques et pratiques sont présentés sous forme graphique; de plus, les débouchés et le nombre vendu sont précisés et, enfin, l'analyse de rentabilité favorable est commentée.

**Évaluation du bogie articulé.** V. Khatchadourian, chercheur principal, CP Rail, Montréal, Qué.

La section Recherche et Développement de CP Rail a procédé à des évaluations en service de deux types de bogies articulés, le Barber-Scheffel et le DR-2, les premiers ayant accumulé depuis leur entrée en service payant, en janvier 1982, près de 400 000 milles et les deuxièmes 150 000 milles, également en service payant.

Le mémoire présente les résultats de profilométrie des roues de ces deux types de bogies, ainsi que ceux, commentés, de l'inspection exhaustive d'un bogie articulé démonté. Enfin, il décrit les essais de fatigue en laboratoire sur les bras de direction du DR-2.

D'autres types de bogies articulés ont été évalués en 1984 et 1985 pour en connaître la stabilité de marche aux vitesses élevées et le comportement dans les courbes, à savoir celui à liaison croisée des longerons de 100 tonnes et le type "élasto-cushion rigidifié" de 70 tonnes. Les résultats sont également présentés.

En 1986, CP Rail a mis en service le premier train-bloc charbonnier comportant des wagons équipés pour une moitié des bogies Barber-Scheffel et pour l'autre moitié de DR-2, dans le cadre d'un programme d'essai brièvement décrit dans le mémoire.

**Modélisation du comportement thermique des wagons-citernes.** A. Michael Birk, ingénieur principal, Davis Engineering Limited, Ottawa, Ont.

Un programme informatique a été mis au point permettant de simuler le comportement d'un wagon-citerne et de son contenu sous l'action d'un feu extérieur, dans le but de déterminer l'efficacité d'un certain nombre de dispositifs de protection visant à atténuer les risques d'explosion, suite à une rupture d'origine thermique.

Ce programme permet de figurer le comportement d'un récipient cylindrique quelconque (un wagon-citerne, par exemple) rempli d'un produit pétrolier léger comme le propane ou le propylène, pris dans des flammes enveloppantes ou à effet de torche. Les mouvements oscillatoires en roulis et tangage du récipient peuvent être pris en compte.

Grâce à ce modèle, il est possible de calculer la pression intérieure, la répartition des températures de paroi, les températures moyennes de la cargaison, le débit de rejet par les soupapes de sûreté, le niveau du liquide, les contraintes dans les parois en fonction du temps écoulé depuis le début de l'incendie et, enfin, le moment de rupture. La validation du modèle a été faite à partir des données expérimentales obtenues d'essais sur des maquettes réduites au 1/5 ou sur des wagons-citernes en vraie grandeur, remplis de propane.

Il est maintenant possible de simuler le comportement thermique des dispositifs de protection suivants, soit séparément, soit en les combinant ensemble: garniture en matériau isolant, blindage contre le rayonnement thermique, dispositif interne de protection, dispositif de sécurité à bouchon fusible, soupapes de sûreté.

À titre d'exemple, le mémoire donne le résultat des essais de validation faits à l'aide de citernes ne comportant pas de tels dispositifs et soumises à des flammes enveloppantes et à un jet de gaz enflammé. Il donne aussi le résultat de la simulation concernant des citernes garnies de diverses épaisseurs de matériau isolant.

**Train-bloc à haute productivité.** D.N. Ferrance, ingénieur-projeteur, Transportation Technology Limited, Kingston, Ont.

En 1984, l'Association of American Railroads (AAR), a lancé un programme ambitieux visant à promouvoir la mise au point d'une nouvelle génération de trains dits à haute productivité pour le transport de marchandises, vrac ou intermode. Reconnaissant la nécessité de cette évolution, le CDT a financé la phase I d'un programme suggéré par la Transportation Technology Limited visant à relever le défi lancé par l'AAR. La recherche a débouché sur deux concepts distincts, dits Intermédiaire et Avancé.

Le mémoire ne traite pas du premier, proposé en deux variantes: trains porte-conteneurs et trains rail-route, devant permettre des réductions du coût d'exploitation de 20 p. 100 environ, et dont la mise en oeuvre ne prendrait pas plus de deux ans. Ses caractéristiques sont: wagons courts à deux ou trois essieux, attelés par des barres de traction sans jeu, les conteneurs étant portés à cheval sur deux wagons.

Le mémoire traite, par contre, du concept dit Avancé, appliqué au transport intermode de marchandises. Il offre des économies de 50 p. 100 et une grande souplesse opérationnelle. Le délai pour sa mise au point et ses essais est de quatre ans. Il se caractérise par des wagons porte-conteneurs de structure monocoque, une traction assurée par des motrices réparties dans la rame, un poste de conduite centralisé et des bogies orientables à essieu unique. Bien que novateur, ce concept est réalisable puisque la technologie à mettre en oeuvre existe déjà ou ne tardera pas à être mise au point dans des applications industrielles.

## Atelier 4 - Installations de sécurité

**Surveillance en queue de train.** Dr. R.J. Pomeroy, vice-président, DSL Dynamic Sciences Ltd., Vancouver, C.-B.

Les pressions économiques ont conduit les compagnies de chemin de fer à rechercher des moyens pour réduire leurs coûts d'exploitation. Cette recherche a débouché sur un dispositif de surveillance placé en queue de train. Il comporte une unité de contrôle-détection montée à l'arrière du train, qui transmet à un module d'entrée et d'affichage dans la cabine de conduite les valeurs de pression de freinage et le sens de rotation des roues du dernier wagon, ainsi qu'un odomètre à commande manuelle qui mesure la distance parcourue à partir d'un point repère. Le matériel assurant ces fonctions est en service opérationnel aux États-Unis depuis juillet 1984 et a passé avec succès le stade de la mise en service expérimental au Canada. À la demande des autorités canadiennes, ce matériel a été perfectionné par une fonction supplémentaire qui consiste à déclencher le freinage d'urgence à partir du dernier wagon, sur un signal transmis par la locomotive.

**Les "LED" en signalisation ferroviaire.** J.A. Lougheed, directeur de la recherche, W.R. Davis Engineering Ltd., Ottawa, Ont.

L'auteur du mémoire commence par des notions fondamentales concernant les propriétés optiques des feux de signalisation à grande portée et décrit le rôle joué par le CDT dans les recherches visant à relever la fiabilité et la sûreté de ces dispositifs. La signalisation fait encore appel à des feux uniques produisant les trois couleurs réglementaires au moyen d'un oculaire mobile mû électriquement. Cette recherche visait à trouver des moyens de se prémunir contre la disparition du signal et contre le bris des pièces mécaniques, la solution étudiée étant l'emploi de diodes électroluminescentes (LED) haute intensité lumineuse pour produire électroniquement les couleurs nécessaires.

Le mémoire fait un tour d'horizon de la technologie considérée dont il présente les avantages et les inconvénients par rapport aux feux à lampes à incandescence et explique l'approche adoptée. Il souligne les propriétés optiques différentes des LED et présente deux concepts prometteurs pour une portée maximale. Le mémoire fait état des difficultés posées par la nature qualitative des prescriptions concernant la visibilité des feux et explique les méthodes utilisées pour chiffrer les résultats des essais de visibilité effectués sur les prototypes.

Il donne les caractéristiques optiques de l'ensemble emboîtable pouvant être installé en rattrapage et dont un prototype a été remis au CDT. Ce feu a une portée de 800 m en plein soleil, dépassant la portée minimale exigée, mais il ne satisfait pas au critère de portée égale. Les rouges ont une portée beaucoup plus grande que les jaunes et les verts, différence qui s'explique par la plus faible luminance de ces deux derniers. En outre, le meilleur vert obtenu est moins bleuâtre que ne le veulent les prescriptions, bien que les personnes dont la vision des couleurs est considérée comme normale l'aient trouvé adéquat au cours des essais effectués.

**Modélisation d'un terminus intermode.** P.R. Rossi, M.A. MacIsaac, E.D. Brown, I.A. Grunwell, Service de la recherche opérationnelle, Chemins de fer nationaux du Canada, Montréal, Qué.

Ce modèle simule les opérations d'un terminus intermode pour conteneurs: chargement et départs des trains, arrivées et déchargement, stockage des conteneurs intermodes, livraison des conteneurs. Il comporte un module de simulation par lots et un postprocesseur infographique. Il permet d'évaluer l'agencement de diverses installations, les échanges de matériels ainsi que les méthodes d'exploitation. Il a servi lors de la conception d'un terminus de conteneurs à Montréal et il sert à l'heure actuelle à évaluer l'effet des variations de trafic sur l'exploitation de terminus situées tant à Montréal qu'à Toronto.

**Système avancé de commande des trains.** B.E. Mrazek, ingénieur, Telecommunications Consultant, Vancouver, C.-B.

Le mémoire commence par un bref aperçu des recherches lancées par BC Rail au début des années 70 et de 1979 à 1984 sur le système de localisation, d'identification et de commande automatiques des trains (LIC). Il décrit le système avancé de commande des trains (SACT) parrainé conjointement par l'Association canadienne des chemins de fer et l'Association of American Railroads, qu'il fait suivre d'une description des tentatives faites par BC Rail de mettre le SACT en oeuvre sur la ligne North Vancouver-Squamish en lui intégrant des éléments compatibles du LIC.

Le mémoire décrit le SACT adopté par BC Rail, tant au niveau des composants qu'au niveau des fonctions qu'ils assurent. Il comporte les éléments suivants:

- ordinateur central
- interface homme-machine
- programme de gestion
- télécommande des terminaux
- équipement radioélectrique
- affichage en cabine
- affichage en queue de train
- affichage au sol
- communications - équipes d'entretien de la voie

En outre, une description détaillée est donnée:

- du protocole de transmission des données et des solutions qui ont permis de résoudre les problèmes s'y rattachant;
- de l'affichage en cabine et notamment de l'interfaçage entre l'ordinateur central et les processeurs des périphériques;
- de l'information infographique affichée en cabine.

**Système avancé de commande des trains.** E.W. Baynton, surintendant général, Transport-Exploitation et Développement, CP Rail, Montréal, Qué.

Ce mémoire fait état des progrès réalisés à ce jour sur le système avancé de commande des trains étudié par cette compagnie.

Grands objectifs fixés à la commande automatique des trains en matière de sécurité, rentabilité et fiabilité. Publication des exigences opérationnelles telles que définies par un groupe de travail représentant sept chemins de fer, cinq canadiens et deux américains. Ce groupe, auquel se sont joints les représentants de deux autres grands chemins de fer américains, agit maintenant comme comité de direction du projet considéré. Tenue de deux grandes assemblées publiques pour la diffusion de l'information aux autres chemins de fer ainsi qu'aux fournisseurs. Les efforts portent maintenant sur l'étude systémique de la question.

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## 1. INTRODUCTION

Rail freight research and development has been an important part of the overall program of the Transportation Development Centre (TDC) of Transport Canada since its formation in 1970. Of particular importance has been the five-year Augmented Rail Freight R & D Program (ARFP) which ended as of March 31/86 and which was an outgrowth of the Rail Research Plan 2000 prepared in 1980 by the Railway Advisory Board (RAB). The ARFP included 86 different R & D project within four areas of research - motive power, freight cars, track, and signalling and communication. Over its five-year life, total expenditures, including those made by Canadian railways and suppliers, have been substantially in excess of $14 million.

Including the ARFP, TDC has funded some 275 rail freight R & D projects over the past 15 years, of which approximately 240 have so far been completed. Each completed project has been documented by a technical report prepared by the contractor who carried out the work. On the basis of field of interest, copies of the reports have been distributed to researchers, other individuals and libraries. Copies may also be obtained free-of-charge upon request to TDC while supplies last.

The primary objective of the seminar was to bring the large body of information contained in these technical reports to the attention of a larger segment of Canada's scientific community and railway operating personnel, thereby directly enhancing its benefit to the railway industry, and, indirectly, to Canada as a whole. To this end, papers on 25 of the more significant projects within each of the four R & D areas were presented on the first day by speakers who had been involved with the work - contractors, railway officers of TDC officers. Additionally, an information package was provided to each delegate, comprised of a listing of the report numbers and titles for the approximately 240 completed rail freight projects plus project profiles for those projects not as yet completed.

The secondary objective of the seminar was to obtain opinions regarding the usefulness of cooperative research such as has been carried out under the program and recommendations as to the nature of future work that might be undertaken. This was accomplished by means of an open discussion held during the final session of the open meeting of the RAB held on the second day of the seminar.

## 2. PROCEEDINGS: THURSDAY, JUNE 12, 1986

### 2.1 Opening Remarks

MR. P.J. DETMOLD (Chairman - Railway Advisory Board): Good morning ladies and gentlemen. I am Peter Detmold, Chairman of the Railway Advisory Board and Chairman for this meeting. I welcome all of you to this seminar. Je vous souhaite la bienvenue à ce colloque, messieurs et mesdames.

We are here to talk about cooperative research in our industry. Perhaps I should start things off with a question. Why is cooperative research so important to the railway industry? I believe it has to do with the importance of standards in the industry. A standard track gauge, for example, is fundamental to the economics of the rail transportation system in North America. Equally fundamental, is an ability for individual supply companies to manufacture products that will satisfy the requirements of at least most of the North American railways. This would not be possible, except at prohibitive cost, if there were not a high degree of standardization within the railway industry.

If industry standards are important today, there is no reason to believe their importance will diminish in the future. The problem is how to avoid major diversities, if each railway, in its separate search for increased productivity and safety, comes up with its own truck design, its own locomotive design and so on. Cooperative research will certainly lessen the possibility.

Thus, we need to cooperate in matters of research and development, and not just with respect to short term R & D. There is another, perhaps more important reason. We need to get together to look ahead to determine what we are going to need in ten years time, and write the requirements for it. Then we will have some chance of getting what we need, when we need it. It is only fair to our supply industry (I see many from our supply industry here today), to give them some idea of the way we are thinking and probably to think together with them about these things. If we don't do this, taking into consideration the lead time it takes to develop our products, how on earth can they have them available for us? Obviously then can't!

We are here to talk about the cooperative research program. Today will be devoted to what has been done, and tomorrow, to what should be done next. I do hope that you will come to the meeting tomorrow and, having heard what you will hear today, tell us what you think about it and what you think we ought to be doing in the next few years.

Now I will introduce Ted Rudback, Executive Director of the Transport Canada Transportation Development Centre.

Mr. N.E. RUDBACK (Executive Director, Transportation Development Centre): Thank you Peter.

Bonjour mesdames et messieurs. C'est un grand plaisir de vous souhaiter la bienvenue de la part de Transports Canada a ce séminaire sur le R&D en transports ferroviaires des marchandises.

On behalf of Transport Canada, it is my pleasure to welcome you here this morning.

Rail freight research and development has played an important part in TDC's research and development program since the establishment of TDC in 1970. This reflects the importance of the 4 billion dollar railway industry to the Canadian economy and the position of the railway industry as the backbone of our transportation system. In 1980, the Railway Advisory Board prepared a paper, "Rail Research Plan 2000". This led to Federal Government approval of the five-year Augmented Rail Freight Transportation Research and Development Program (ARFP) in 1981. Ten million dollars of additional funds were provided over this period of time. The program was carried out in general accordance with the lines of R&D proposed by the railways and in cooperation with them. The railways contributed to this augmented R&D program, and we have seen a real spurt of innovation. We will be reviewing many of these projects and I think you will agree that the results are impressive. It shows what we can do when we set targets and work towards them cooperatively.

After five years it is quite appropriate to look at where we are, what we have achieved, and at the same time look ahead. The look ahead will take place tomorrow morning at an open meeting of the Railway Advisory Board. I hope as many of you as possible will be able to attend. Part of the process of looking ahead is to examine what we have achieved and that is part of the program today. The results are going to be reviewed in a few minutes by Bill McLaren, and will be the subject of detailed technical presentations.

The approval of the ARFP in 1981 marked a change in Federal Government and Transport Canada policy. It ended a period of declining emphasis on research and development and began a period of renewed activity in research and development which is still with us.

We work in a rapidly changing environment and priorities continue to evolve. The program we are reviewing today was aimed principally at productivity and encouraging industrial development and innovation. It succeeded in doing that. It has a by-product of increased safety, which I believe goes hand in hand with improved productivity. Now we are in a period where the Government is proceeding with economic regulatory reform. Transport Canada is moving very quickly towards removing some of the regulatory constraints under which the railways must operate. These constraints hindered their ability to compete effectively with other modes, and I believe that within the next year or so we will see that situation change dramatically for the better. We are also living in a period of budgetary constraint, which means that everything we do has to be justified even more carefully than before.

I am encouraged to believe that Transport Canada is still interested in and prepared to support R&D, but the nature of what we are going to do is changing. We will be looking more at mission type R&D in response to Transport Canada's internal requirements for improved air traffic control, ice breaking and ice breaking technology, and similar services where the Department has a direct operating responsibility. External R&D will emphasize transportation safety, and that is why I think it is important to keep in mind this link between safety and productivity. The unsafe system is not very productive. The railways have an impressive record in the safety field, but as impressive as it is, there is always room for improvement and we must always strive for improvement. I said that ARFP activities were directed at productivity and had safety as a by-product. In the future I think Transport Canada will encourage safety-type R&D which will have productivity as a by-product. The basis for continuing cooperation will remain.

These comments will be discussed in more detail at our open meeting of the RAB tomorrow. Would you keep them in mind as you are looking at the program and discussing the technical results.

I will now give the microphone to Bill McLaren, who is Chief of Current Technology at TDC. He has been responsible for managing Transport Canada's portion of the ARFP, and he will provide an overview of the program.

## 2.2 Rail Freight Research and Development Program Overview

Presentation by Mr. W.S.C. McLaren, Chief, Current Technology Division, Transportation Development Centre, Montreal, Que.

First of all, I would like to say that it is gratifying to see that the Seminar has attracted such a strong attendance. I hope that you will find the seminar worthwhile, both because of what you may learn from the presentations and the discussion, and because of the opportunity it gives to meet informally with others who share common interests.

Last September, Bob Mayes, Director General of R&D for Transport Canada asked TDC to organize a seminar on Rail Freight R&D. The purpose of the seminar would be to disseminate the results of the Rail Freight R&D Program more widely in the railway community and to review the program as a whole with a view to deriving future directions. The timing of the seminar in the spring of 1986 was chosen because this would mark the completion of the five-year Augmented Rail Freight Program, or ARFP.

Before getting into a description of the Program which is the subject of the Seminar, I would like to say a few words about its scope. The projects covered deal, with one important exception, with projects which form part of the Transportation Development Centre/Railway Advisory Board or TDC/RAB Rail Freight Program. This program is the result of cooperative arrangements made between the Railway Association of Canada and Transport Canada concerning R&D in rail freight. The coordinating mechanism at the program level for this effort is the Railway Advisory Board which advises Transport Canada on R&D matters concerning railway transportation. This also explains, for those of you not familiar with these arrangements why, for the second day of the Seminar, the proceedings will be in the form of an open meeting of the Railway Advisory Board which all attendees at this seminar are invited to attend.

I mentioned one important exception to the presentations being on projects which are part of the TDC/RAB Rail Freight Program. The exception is the presentation this afternoon on the ATCS or Advanced Train Control System project. As most of you will already know, the ATCS project is sponsored by the Railway Association of Canada and the Association of American Railroads and it has no direct relationship with the TDC/RAB program. I understand, however, that the ATCS concept originated in the work of the Signalling, Control and Communications Working Group of the RAB, so that makes ATCS a close relative of our program. In addition, Peter Detmold, besides being Chairman of the Railway Advisory Board is General Manager of ATCS. At any rate, this is a welcome opportunity for us to hear about this undertaking which is of such consequence to the railway industry.

Just to complete my discussion of the scope of the program being described today, let me just emphasize that it does not include the large body of R&D effort carried out independently by other organizations, notably the railway research departments and others involved in R&D in rail matters. Perhaps at some future date a conference or seminar with an expanded scope to include such work would be of interest to the organizations represented here. For the moment, however, the scope of the present program seems to have provided plenty of interesting material to fill our day.

The Rail Freight Program is above all a cooperative venture, drawing on the resources and talents of many organizations from different sectors of the railway industry, from government, from universities and research organizations. To illustrate this here are just a few statistics:

i) six railway companies have participated and contributed resources to the program: CN Rail, CP Rail, BC Rail, Quebec North Shore and Labrador Railway, Ontario Northland Railway and the Cartier Railway Company.

ii) 35 different contractors have been involved in carrying out the work, of which four have made resource contributions

iii) federal government contributions to the program have been made through the Transportation Development Centre of Transport Canada acting as program manager as well as a program sponsor. Additional contributions to the program have been provided from the National Energy Program, and the Unsolicited Proposal Program. The National Research Council of Canada has contributed substantially to the program through in-kind research contributions.

iv) international collaboration has been achieved through the auspices of the Memorandum of Understanding with the U.S. Department of Transportation (Jamieson/Volpe agreement).

v) coordination with the North American railway R&D effort has been achieved through membership on the Track Train Dynamics Steering Committee and information exchange with the Research and Test Department of the Association of American Railroads.

Because of the number of people here today who may not be familiar with the Transportation Development Centre, I would like to say a few words to clarify its role in the Rail Freight Program. TDC is the centralized research and development arm of Transport Canada. When TDC was formed (as the then Transportation Development Agency) Montreal was chosen as its location because of its role as a centre for transportation, a role, by the way, that the city still holds according to the article "Montreal is still Canada's prime mover" which you may have seen in a recent issue of the Montrel Gazette.

The principle operational function of TDC is project management. Projects are managed by a team of professionals, engineers for the most part, given the technical focus of TDC's program. The majority of TDC's program is contracted out to private sector organizations. In many cases projects are cost-shared, resulting in a variety of contracting arrangements.

TDC prepares each year an operational plan which defines in each transportation mode the general objectives and sub-objectives of the program. The preparation of the Operational Plan begins each year in early fall and a draft of the plan is presented to groups within the federal government and to the Railway Advisory Board, normally in January. In the case of Rail Freight activities, most projects originate in proposals from the private sector. In most cases the proposer, if not a railway, must have railway sponsorship in order to ensure that the project addresses a real development need. This way there is the likelihood of a future client to apply or make use of the results of the research or development. The screening criteria for projects will vary according to the specific objectives and priorities of current programs but are laid out for each planning year in the Operational Plan.

As Ted has already noted in his welcoming address, the Transportation Development Centre has sponsored R&D in cooperation with the railways since the early 70's. The program received a significant boost in 1981 with the start of the Augmented Rail Freight Program (ARFP). This program added approximately $2 million per year to the TDC rail freight budget and about $9 million over the five year period. This compares with about $1 million per year which has been available from our base budget. Thus, the ARFP has represented a very significant augmentation of the funds available to TDC for rail freight R&D.

The origin of the ARFP may be traced back to 1980 when Railway Advisory Committee Chairman Peter Detmold submitted to Transport Canada a comprehensive proposal for a joint government/industry railway research program entitled "Rail Research Plan 2000". In response to this proposal submissions were prepared by Transport Canada to secure a special allocation of funds in support of a rail research program. Program approval was obtained and implementation started in June 1981, five years ago this month.

The purpose of this Seminar is to tell the story of the Program and to highlight some of its accomplishments. However, with over 80 projects and about the same number of reports published, there is just not the time to tell the story of every project. Naturally we have tried to select some of the more interesting projects for presentation while at the same time achieving a balance in the selection so as to cover the work of the diverse group of organizations involved: railways, universities, research laboratories, consultants, and industry as well as representing the spectrum from applied research to demonstration. We have also had to consider the fact that some of the projects will be described in papers to be presented at the Third International Heavy Haul Conference to be held in Vancouver in October. If you are interested, by the way, we have invitation booklets for that Conference available here today. In order to provide information on aspects of the program not already covered in today's program, your registration package includes information on other Rail Freight R&D activities, both completed and ongoing.

I would like now to talk in general terms about the accomplishments of the program as an overview of what you will be hearing today.

You will be hearing about the establishment of a modern 50kV electrification on the Tumbler Ridge branch line of B.C.Rail and the Rail Freight program activities to provide documentation of the demonstration from design through to operation. This electrification is only the third of its kind in the world. As a result of this work there is the capability in Canada to evaluate future investment decisions on electrification with greater confidence and there is a detailed knowledge of the industrial capability in Canada to undertake the various engineering, manufacturing and construction tasks involved.

One of the most significant developments in locomotive traction in recent years is the application of three phase a.c. induction motors to railway traction. A project to apply this technology to a locomotive for evaluation purposes has been underway for some time now under an arrangement between C.P.Rail, Bombardier, BBC Brown Boveri Canada and the Department of Regional and Industrial Expansion. TDC, under a separate arrangement with BBC, is co-funding the parallel development of a microprocessor control system for this traction system.

Under a cost shared arrangement with Bombardier Inc. two single cylinder medium speed diesel research engines have been designed and manufactured and installed at Bombardier's test cell facilities in Montreal. This engine has attracted interest from engine research groups around the world. One engine has been acquired by the National Research Council for their heat engine laboratories in Ottawa.

You will hear about work on locomotive event recorders, devices which are likely to perform an important role in future in improving safety through improved training and accident investigation.

All of these projects will be covered in this morning's Motive Power Session.

We will be hearing about projects being carried out by the Canadian Institute of Guided Ground Transport, Queen's University and others on track structure research. Another paper will describe work on improved steels capable of giving longer life for trackwork components such as frogs. Wheel and rail wear and fatigue is the subject of experimental research at the Vancouver laboratories of N.R.C. and the N.R.C. Vehicle Dynamics Laboratory in Ottawa is working with TDC and an industry steering committee to finalize the design of a new wheel/rail system test rig. All this work will be described in this morning's Track and Infrastructure session.

We have two very full and interesting sessions lined up for the afternoon, Session 3 on Freight Cars and Session 4 on Signalling and Communications.

The Freight Car session will cover train dynamics, train resistance, truck developments and examples of new intermodal train concepts developed by Transportation Technology Limited.

The train dynamics work derives from early research carried out by CN on the simulation for their training centre at Gimli Manitoba. The project which TDC has sponsored entails the translation of this early software into a real-time digital simulation suitable for use as a research tool to study longitudinal train action.

Train resistance is a subject which was launched into prominence by the oil price escalation of the 70's. While the subject today has less of a sense of urgency, significant savings should be possible through the application of improved knowledge of train resistance. Two presentations this afternoon deal with this subject.

The radial axle or self-steering truck has been the subject of jointly sponsored research projects with CN Rail and CP Rail since the early 70's. A conference on "The Economics and Performance of Freight Car Trucks" held in Montreal in 1983 resulted in the publication of much of the North American work in truck development up to that time. Two presentations today will bring us up to date on some of the recent freight car truck developments.

The High Productivity Integral Train presentation, which completes the Freight Cars Session, describes integral train designs developed under the guidelines issued by the Association of American Railroads (AAR) for the High Productivity Integral Train project. The concepts were developed under contract to TDC and have been presented by the designers to the AAR for evaluation. The initial phase of the project entailed the preparation of guideline specifications for the designs to meet Canadian railway requirements.

The Signalling and Communications session opens with a presentation on end-of-train monitoring, a relatively new and important development with significant potential for productivity improvement. There will be a presentation on a project on the application of Light Emitting Diode technology to railway colour light signals. A container terminal simulation model will be described which provides a comprehensive design tool for intermodal terminal design, complete with an extensive computer graphic capability. The last two presentations in this session are by B.C.Rail on the LICS train control system work followed by the presentation which I mentioned earlier by Ed Baynton of C.P.Rail on the RAC/AAR Advanced Train Control System project.

As mentioned earlier, the limited number of presentations which we were able to include in the Seminar means that there are many projects which have not been covered. To overcome this limitation we have included in your folder two documents which should be of assistance in obtaining further information. The first is a list of TDC reports on Rail subjects completed since 1979. This includes both Rail Freight and Rail Passenger reports and includes about 280 references. The more recent titles are listed first. In order to provide information on on-going projects a set of project profile sheets has been included which has drawn on information on 36 active Rail Freight projects being tracked in our Management Information System.

One other item is included in your folders which I would like to draw your attention to at this time, and that is the questionnaire. It is quite short and easy to complete, so I would like to ask all attendees to please remember to fill in the questionnaire before you leave the Seminar and leave it at the Registration Desk on your way out. If you are not planning to return for the Friday Session please leave it when you leave today.

We will be reconvening tomorrow in this room for the open meeting of the Railway Advisory Board. It will be in tomorrow's session that we hope to obtain the most useful feedback and discussion relating to the R&D program and its future direction. I hope that all of you are planning to attend.

Thank you.

## 2.3 Introduction of Chairmen of Technical Sessions

P.J. DETMOLD: My job now is to introduce to you your Session Chairmen. First of all, there is Steve Cavanaugh, Assistant Chief Mechanical Officer, C.P. Rail, who will chair Technical Session No. 1, Motive Power, in Salle des Saules immediately after the coffee break. Michael D. Roney, Manager of Track Technology, C.P. Rail, will chair Technical Session No. 2, Track and Infrastructure, meeting in Salle des Pins at the same time. I should say that Mike Roney would not have been chairing the session if Rick Richardson, who is the Task Force Chairman for Track Engineering, had been available.

Until very recently I was a CP Rail officer. I am now employed by the Railway Association of Canada and I say this to assure you that in the selection of Session Chairmen, there was no CP bias involved. I am therefore somewhat relieved to introduce Bob Radford, Chief Mechanical and Electrical Engineer, Canadian National, who will chair Technical Session No. 3, Freight Cars, in Salle des Saules right after lunch. The chairman of Technical Session No. 4, Signaling and Communication, to be held in Salle des Pins after lunch, is Doug Walkington, Deputy Director of Signals and Communications, CP Rail.

It was courteous of Bill McLaren to mention that the Advanced Train Control System Project (ATCS) is an independently funded organization, organized by the Railway Association of Canada and the Association of American Railroads. I acknowledge, as Executive Director of ARTCS, that it did come into being out of this RAB joint research. In both the original 1978 program and the 1980 Rail Research Plan 2000, there is an item on Train Control which reads: "A simple form of transponder fitted between the rails at the approach to local stations and other significant places, would inform the dispatcher of the location and speed of the trains in his area, enabling him to pass revised instructions to the engineman through an electronic cab display. This also serves to remind the engineman of existing train orders and local route information. A computerized installation provides the dispatcher with a continuously up-dated display of all the traffic in his area with the capability of warning him if there is any danger of conflicting train paths". There is therefore some kind of relationship between ATCS and our work.

There is coffee outside and we will reconvene in Salle des Saules or Salle des Pins. Thank you very much.

Editorial Note:

The remainder of the first day of the seminar was devoted to the presentation of papers in four separate technical sessions - two in parallel in the morning and two in parallel in the afternoon. Each session dealt with one of the four principal areas of the R&D program - motive power, freight cars, track and infrastructure, signalling and communications - and was chaired by a member of the particular Railway Advisory Board Working Group concerned with that area. Each paper described one of the more significant projects within the R&D program. The 25 papers presented during the four technical sessions are reproduced in full in the remaining portion of this Section 2. Each paper is followed by the discussion which took place on completion of the author's presentation, except in the case of the three papers presented in Session #2 by the Track Structure Research Panel members during the final part of that session. In that particular case, the discussion on all three papers follows the final paper.

## 2.4 Technical Session #1 - Motive Power

### Session Chairman

Mr. S.D. Cavanaugh
Ass't Chief Mechanical Officer
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# RAILWAY ELECTRIFICATION

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(Transcribed from tape of Seminar Proceedings)

## ABSTRACT

TDC's program of research and development in rail electrification has been oriented towards preparing Canada for possible future electrification of certain sectors of the country's rail system. To that end, TDC has supported research in the following areas: establishing the technical and economic characteristics of electrification; developing guidelines for electrification including those needed for signalling and communications; evaluating alternative electric and hybrid locomotive designs; and, identifying the system requirements and the related costs of specific electrification projects. A brief description of the work done or still in progress in each of these areas is given.

# RAILWAY ELECTRIFICATION

Good morning ladies and gentlemen.

This morning I would like to give you a brief overview of the railway electrification program at TDC. This program encompasses many projects, so I will not be able, in the time allotted to me, to go through any technical details of the project. I want to make sure, though, that you are aware of the objectives behind the program, the areas that the program touches upon, and the key projects in the program.

To start with, the objective of this program was to develop experience with electrified railway systems in Canada in preparation for possible future electrification of certain sectors of the Canadian railway network.

TDC's program addressed, and still addresses in some ways, four research areas. The first area addressed establishment of the technical and economic characteristics of electrification. The second area looked at developing guidelines for electrification, and these guidelines could eventually become important standards for railway electrification. Also we looked at alternative electric and hybrid locomotive designs, and finally we tried to address the system requirements aspect of electrification by doing related cost benefit studies of specific electrification projects.

In the first area, the backbone project or activity was the railway electrification demonstration that took place on B.C.Rail. I don't have time to go through all the history behind it, but just to say that in 1981-82 the opportunity arose on B.C.Rail to stage a railway electrification demonstration. This was the first railway electrification demonstration in Canada, the first electrification at 50 kV 60 Hz, and on a line that is representative of mainline operation through the Rockies in Canada. The objective of the demonstration was to develop, test and evaluate the equipment suitable for national railway electrification - not just equipment that would be tailored to a very small specific operation but an operation that is really typical of a large scale operation. Thus, what was done under the demonstration would apply directly and readily to any electrification project in Canada.

Under that demonstration we had some specific R&D projects. One was addressing the design and sourcing of power supply for the line and another was on the design and sourcing of a 50 kV catenary system. We also looked at testing and evaluating electric locomotives, some field evaluation of the catenary physical installation, and we developed operation and maintenance manuals. Finally, we addressed the feasibility of LICS under 50 kV electrification.

In the second area of our activity, we focused mainly on the railway electrification guidelines. Preliminary work that was done by CPCS, and by CIGGT, provided the ground base for addressing the subject at the Canadian Standards Association level. About 18 months ago we went to CSA with these preliminary documents and asked them to come up with a document that would be a recognized CSA document. We now have this document. It is not on your list of available reports, because it is not a TDC report. It is a preliminary document that is now being floated to the international community of various railway electrification standards organizations and suppliers. After one year,the comments and questions received will be reviewed, analyzed and incorporated in the document and the document will be published as the first edition of these guidelines.

We also had some peripheral projects to the development of these guidelines, because we needed some technical data that was not available when we started to work on the matter. These included work to establish minimum air-gap clearances for 50kV operation, also the impact of electrification on existing clearance standards such as for highway overpasses and railway structures in general. We also did some tests on different mast design configurations to see whether we could achieve certain economics by going away from the standard mast design and using worn rails as masts when and where it might be warranted. Finally, we are looking at the catenary deflection under wind and ice loading. This is to try to come up with a computer model that will be calibrated against field testing in order to establish the most economical design for the catenary, given that you cannot really realistically use maximum ice and wind and all these loads simultaneously. So we are now developing a model that will allow making some choices and decisions and that model will be calibrated against actual deflections measured under known conditions in the field.

In the third area, we have been looking at alternative electric locomotive conceptual designs because, when B.C. Rail decided to electrify they were really pressed for time; they had only 18 months between the time they decided to go ahead and the date at which the line had to be operational. So they went ahead and they chose a locomotive that was state-of-the-art at that time.

Linked to railway electrification there is always the question of what you do in the transition period, if not also on a long term, about the fact that you might end up with a system having a fleet of diesel electric locomotives servicing some secondary lines and branch lines and maybe a fleet of electrics servicing your electrified mainline. One of the possible technical solutions to this situation is a hybrid locomotive. This is why we had a study carried out to look at the possibilities for hybrid locomotives in terms of establishing the power requirements: that is, the power that we could have on board in the diesel electric mode. A hybrid locomotive, to be able to operate as an electric on its own, requires a higher number of components than is already present on a standard diesel electric. This means that you would have to down-size the diesel power plant somewhat so that a satisfactory package can be arrived at for the railways.

Now we get to the fourth area of our activities and this is really a very important area and a very provocative one, because now that we have the demonstration results in, we are able to do cost benefit studies of specific lines under consideration for electrification and we don't have to use data that has been extrapolated and/or modified from other countries, either from Europe, from the States or even from Japan. We have technical and economc data that was developed here in Canada, that is representative of railway operation in Canada in 1986. We had studies in that area. The first one was the cost benefit study of the extension of the electrification on B.C. Rail from Tacheeda, which is about 130 kilometres north of Prince George, down to Prince George. We also have an on-going study jointly funded by the Federal Government and the Quebec Provincial Government which is looking at rationalizing and electrifying the Quebec North Shore railway network. The reason for the study is that the Quebec North Shore and Labrador Railway, the Cartier Railway, Wabash and a couple of other smaller railways all move iron ore from the mines in the North-East of Quebec to the shores of the St. Lawrence river and each are now operating under capacity in terms not only of mine output but in terms of capacity of the railways. We are now looking at ways to reduce their transportation costs from the mines to the ports. The study started just a few months back but already is showing some promise.

Now just to give you an appreciation of the scope of participants in the railway electrification program at TDC I have drawn this list, and I will just go through it very briefly: we have of course the major railways; we have CNCP Telecom, Bell Canada, the industries like GM Diesel Division, Bombardier Diesel Division, The National Research Council, CIGGT; we also have the standards associations like C.S.A.; we have the Canadian Electrical Association, Hydro-Quebec IREQ, which is the Institut de Recherches en Electricite du Quebec, and also B.C.Hydro. So you can see that a very wide spectrum of organizations have been participating in the program. Some have been funded to do so, some have done so in kind and we want to take this opportunity to thank everybody - all the organizations that have been participating so enthusiastically in the program and also have given us support that we could not have found anywhere else and especially the contributions in kind towards the elaboration of the railway electrification guidelines, were very much appreciated. We are going to make sure that we keep in touch with all of you and that you are kept informed on the developments as we go along,.

Now just to recap briefly the present status of the major projects. The railway electrification demonstration on B.C.Rail is now completed although data is still being gathered and up-dates will be provided on a yearly basis. However, the demonstration as such is completed. We have all of the technical reports in except for the last one, the system documentation, which should be available at the end of this month. This report will contain a complete overview, including technical and economic information, so it will be a most useful document.

On railway electrification guidelines, the preliminary document is out and being circulated for review and comments. The study looking at the electric locomotive conceptual design is also completed and the report is available. The hybrid locomotive study is also completed and the report will be available within a week or so. Also, the cost benefit study of the extension of the electrification on B.C.Rail is done. B.C.Rail are reviewing the situation and will come up with a decision some time this year. The study for rationalization and electrification of the North Shore Railways is ongoing and that is one to follow too, because it is a very interesting combination of system integration, or if you want, network integration, plus augmentation of the possible savings by maybe adding electrification to whatever rationalized network will be retained. And finally we have the catenary deflection under wind and ice loading that is ongoing and the results will be added in due course to the guidelines.

This concludes my presentation. Thank you.

## DISCUSSION ON
## PRESENTATION BY C.A. VERSAILLES

**P.A. LAROSE (CANAC):** My questions are about the operational aspect of eventual implementation of electrification in Canada. Have you considered the impact on peak power demand in your studies? This would appear to be an important factor given the tonnage of trains that we are operating and the tendency to fleet trains which is normally at the convenience of the dispatcher. Would this factor eventually be accounted for in the automatic train system as an additional parameter?

C.A. VERSAILLES: This aspect of power management has been addressed and is covered in the system documentation report on the B.C. Rail demonstration. I don't see why it could not be included as a consideration for automatic train control.

## DSL FUELSAVING DEVICE

G. Levesque
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DSL Dynamic Sciences Limited
Montreal, Que.

### ABSTRACT

A new concept to greatly reduce the wasting of fuel due to idling of locomotives and to the excess of power in a train consist has been fully implemented on five SD40-2 locomotives. The automatic start/stop controller suitable for North American locomotives has been designed paying attention to safety, reliability, cost, ease of installation, operation and maintenance.

To achieve these objectives, full solid-state and micro-processor techniques were used, modern electro-mechanical devices were designed, special structured software techniques were used and practical railway locomotive experience was applied throughout the project.

Savings in the order of 55,000 litres per locomotive, per year, have been calculated from the results obtained during the testing of the prototype system. Five pre-production systems have been installed for larger scale testing.

## 1. INTRODUCTION

### 1.1 Background

The product, just about to be introduced to you, is based on work done by QNS&L in their effort to counteract the mid 70s energy crisis.

Many ways of fuelsaving have been investigated and tested. Graph #1 shows some important parameters related to fuel consumption.

Some significant savings have been achieved, the most impressive one being speed reduction with as much as 8% by going from 40mph to 30mph; another 5% reduction has been demonstrated by increasing train length from 230 cars to 250.

An important area has then been identified for its very large saving potentials, that is, idling of locomotives and excess of power in train consists. Let's try to answer the following question: Why are locomotives kept idling? Traditionaly for three main reasons:

1. To keep the engine warm;
2. To avoid restarting difficulties; and
3. Because fuel was inexpensive.

Fuel being inexpensive soon became no more valid, QNS&L people thought the two other reasons could be eliminated by some sort of automated start/stop system to maintain engine temperature to a safe level. Based on the impressive saving potential calculated from idling statistical data and TOS simulation results, they decided to build a prototype system called ADA to assess the real potential.

The next two graphs illustrate the results of these studies. Here an 8% reduction could be obtained if we apply the start/stop concept to the actual 4 locomotive consists used on Sept-Iles/Labrador City Iron Ore trains. The fact is that most of the time only three (3) locomotives are required, short distances with steep grade require the full available power of four (4) locomotives.

The rectangle on the next graph (#4) represents the total cost of idling locomotive at QNS&L. The cross hatche portion is a conservative estimate of savings if we apply the same start/stop concept. One important point to note on this graph is the fact that savings are more important around summer time which makes the idea even more attractive for railways located further south.

## 1.2 Objectives

Having said all that, this is where DSL got into the picture and joined its railway electronics and software expertise to QNS&L operation and maintenance expertise in a project where the main objective was to provide a practical means for railways to save a significant amount of fuel.

Part of this objective was to develop a system with the following characteristics:

- Low cost
- Easy to install and maintain
- Easy to operate
- Very reliable

An additional objective was to verify, through field tests, the actual fuelsavings and to provide performance data necessary to support manufacturing and marketing of the device.

## 2. PRODUCT STATUS (Graph #4A)

To date, two levels of prototyping have been completed. First, the bench prototype, using simulated locomotive imputs, permitted the development of a controller with an original microprocessor-based, hardware structure. Special electronics and electro-mechanical devices needed to meet the requirements were also designed.

Then, supported by TDC, a second prototype was built. Ruggidized and improved over the first one, it was installed and successfully tested on QNS&L locomotive 241, on SD40-2 model.

The next step was to integrate the findings from the two levels of prototyping along with some design optimization into the pre-production systems. Installation of 5 such systems will be completed before the end of June. Thanks to TDC for their continuing support to collect data using these five (5) systems. Longer term and larger scale fuel savings and system reliability will then be demonstrated.

Another step will be to complete an order with QNS&L to equip their entire fleet before the end of the year. Production is under way and delivery will be completed in September.

# 3. PRODUCT DESCRIPTION

## 3.1 Features (Graphs #5 to 10A)

Before going into any implementation details, let's have a look at the most important features of DSL's Fuelsaving device.

## 3.2 Main Control Unit

The main control unit is a ruggedized, microprocessor-based controller. The hardware structure is similar to the one of a general purpose micro controller. Features are:

- I/O Bus on Back plane
- 6809 Microprocessor CPU Module
- I/O Modules electrically isolated
  - . Quad Solid State Switch Digital Output
  - . Quad Digital Input Module
  - . Magnetic Pick-Up Module
  - . RTD Temperature Sensor Module
  - . Isolation Switch Actuator Driver
  - . Dual Serial Port RS-232
  - . 16-Bit I/O Module
- Floating Power Supply Module

The large variety of locomotive compatible I/O modules makes it a general purpose locomotive microprocessor locomotive controller.

## 3.3 Control Panels

Consist Control Panel support features related to the excess of power in the train. It permits the selective shut-down of locomotive units in the consist. Selected trailing unit is automatically isolated and cycled (Start/Stop), ready to be recalled any time the engineman decides so.

The system control panels provide enginemen and shop personnel easy means to perform the following:

- Setting up locomotive status
  - . Lead Mode
  - . Trail Mode
  - . Trail Number
- Set fuelsaving mode on an independent unit
- Start a unit from the cab
- Run system self test

- Set unit as an ordinary unit with no fuelsaving device
- To provide operator with feedback using visible and audible display panel

## 3.4 Key Control Components

There are components playing critical roles in the functions such as: engine temperature regulation, engine isolation, engine cranking and starting, and engine stopping. They are:

- Isolation Switch Actuator
- Engine Coolant, Temperature Sensor
- Fuel Prime/Engine Start, Solid State Relav Module
- Engine RPM Magnetic Pick-Up
- Engine Governor Solenoide Drivers

## 3.5 Safety and Protection Components

Large portion of the system is dedicated to safety of operation and protection in case of failure. These are:

- Signal Light Driver
- Train Alarm Driver
- Low Water Reset Actuator
- Fuel Cut-Off Switch Sensor
- Automatic Drain Valve Sensor
- Auxiliary Generator Voltage Sensor
- Drain Temperature Switch Sensor

## 4. CONCLUSION

DSL is proud to say that project objectives have been met and we do anticipate that long term testing will demonstrate that in fact we have exceed most of the objectives. QNS&L savings on the overall locomotive fuel bill is estimated to be close or to exceed 10% once fully implemented.

DSL will continue its R&D efforts to further improve the Fuelsaving device and also to find other applications for the micro controller develop under this program. An interesting area where this controller could potentially brings in important contribution to is with the Automatic Train Control System.

DSL

# SOME IMPORTANT PARAMETERS RELATED TO FUEL CONSUMPTION

* FORCES ACTING ON THE TRAIN

- Rolling Resistance
- Wind
- Curves
- Gradient
- Braking
- Tractive Effort

* SPEED

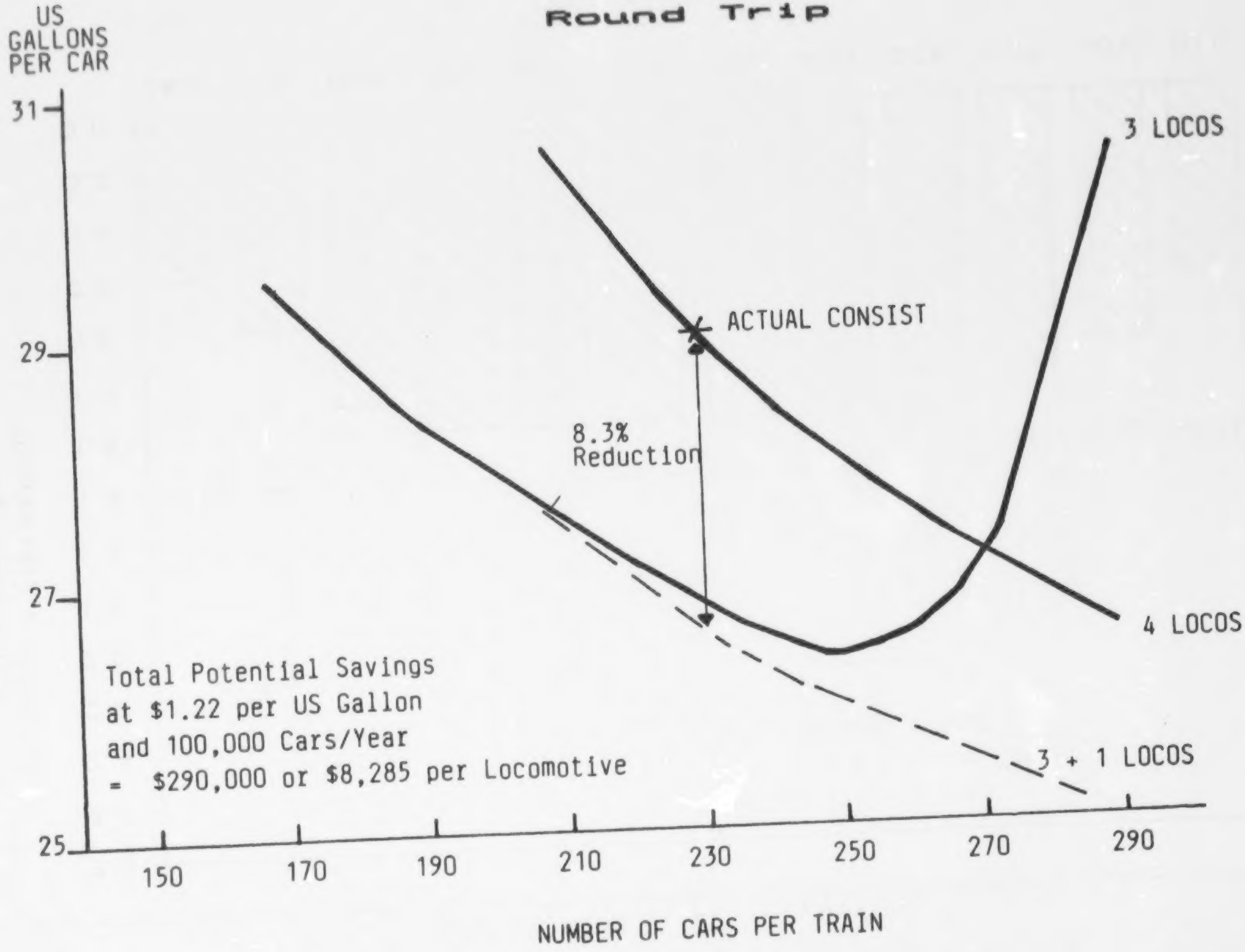
* WEIGHT

* TRAIN LENGTH

* NUMBER OF LOCOMOTIVES

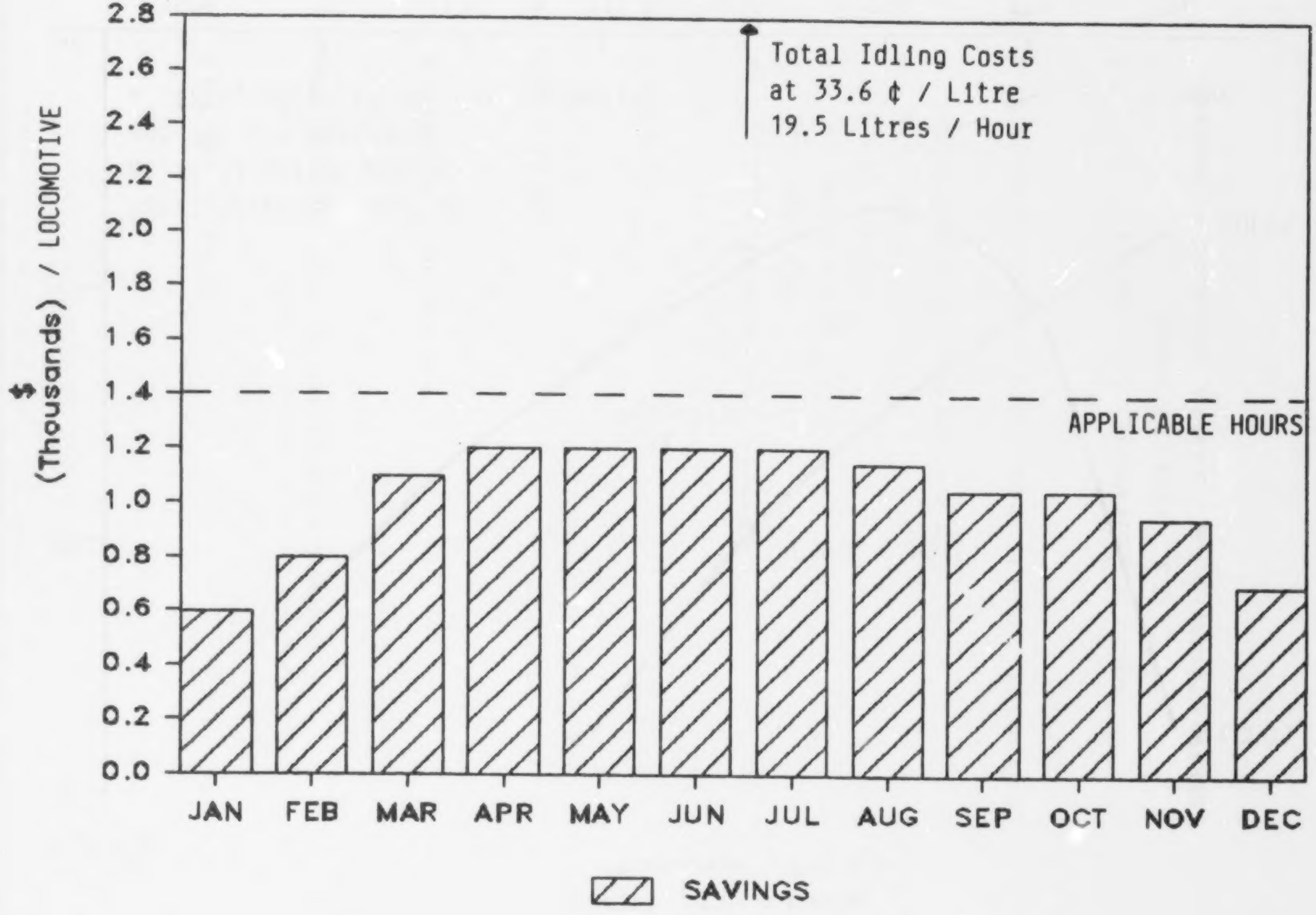
* IDLE TIME

# FUEL CONSUMPTION TREND
## CR Trains
## Round Trip



Total Potential Savings
at $1.22 per US Gallon
and 100,000 Cars/Year
= $290,000 or $8,285 per Locomotive

# POSSIBLE SAVINGS



DSL

# PRODUCT STATUS
# FUELSAVING DEVICE

- ☑ BENCH PROTOTYPING PHASE
- ☑ FIELD PROTOTYPE PHASE
- ☑ 5 PRE-PRODUCTION INSTALLED
- ☐ QNS&L ENTIRE FLEET EQUIPPED
- ☐ EXTENSIVE LONGER TERM TESTING

# SYSTEM FEATURES

* FULLY AUTOMATIC START AND STOP IN FUELSAVING MODE

* YARD OR ROAD OPERATION

* AUTOMATIC ENGINE ISOLATION ON TRAILING LOCOMOTIVES ALLOWS OFF-LOADING OF EXCESS POWER.

* MICROPROCESSOR-BASED, MODULAR CONSTRUCTION FACILITATES UPGRADING AND EXPANDABILITY.

* SELF-TEST FOR EASY SYSTEM CHECK-OUT

* EASY INSTALLATION

# OPERATIONAL FEATURES

- * SYSTEM CONTROL PANEL
  - . Simple Set-Up Switches
  - . Start Button in Cab

- * CONSIST CONTROL PANEL
  - . Mounted on Control Stand
  - . Single Push Button Controls Each Locomotive in Consist

# SYSTEM RELIABILITY

- ALL SOLID STATE
- MAXIMUM USE OF CMOS TECHNOLOGY
  - Low Power
  - Wide Temperature Range
  - Noise Immunity
- OPTICALLY ISOLATED INPUTS/OUTPUTS
- FULLY PROTECTED SOLID STATE RELAY OUTPUTS
- FAILSAFE INPUTS/OUTPUTS

# SAFETY FEATURES

- * PROVIDES AUDIBLE WARNING BEFORE AUTOMATIC START.
- * SYSTEM CANNOT RESTART ENGINE WHICH IT DID NOT STOP.
- * CONTINUOUSLY MONITORS EMERGENCY FUEL CUT-OFF BUTTON.
- * MONITORS ENGINE RPM.

# PROTECTION FEATURES

* SYSTEM CHECKS FOR:

- . Cold Drain Condition;
- . Automatic Water Drain Valve Operation;
- . EFCO;
- . Starter Motor Overload Condition (or Failure To Start);
- . Low Oil Condition;
- . Auxiliary Generator Failure;
- . Locomotive Lights On;
- . Internal Faults;
- . Engine RPM.

* SYSTEM ACTIVATES TRAINLINE ALARM AND SIGNAL LIGHT IF A FAULT IS DETECTED OR IF ENGINE FAILS TO START.

* HANDS-OFF CONDITION IN THE EVENT OF A SYSTEM FAILURE.

# MAINTENANCE FEATURES

* LOCOMOTIVE INTEGRITY MAINTAINED

- Returns to Normal if Control Unit is Removed.

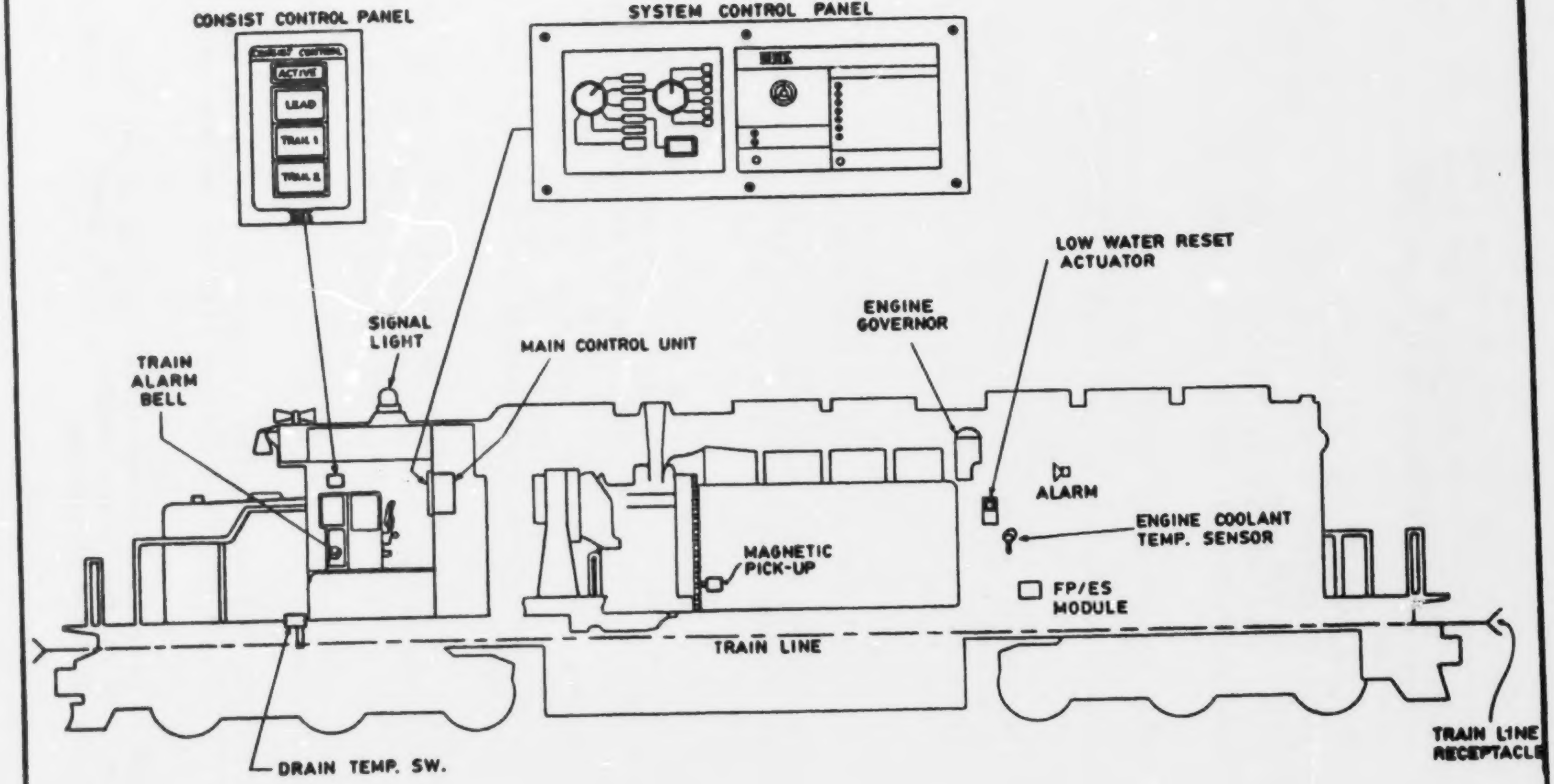
* EASE OF MAINTENANCE

- Accessible Main Control Unit
- Mechanical and Electrical Quick Disconnect
- Sub-Assemblies Designed for Easy Interchangeability

# MAINTENANCE FEATURES
(cont'd)

* BUILT-IN TROUBLE-SHOOTING FACILITIES

- Fault Indicators
- Intelligent Self-Test Feature
- RS-232 Interface Allows:
  - > System Interrogation by Portable Computer;
  - > System Monitoring/ Logging.


CONSIST CONTROL PANEL
CONSIST CONTROL
ACTIVE
LEAD
TRAIL 1
TRAIL 2
SYSTEM CONTROL PANEL
LOW WATER RESET ACTUATOR
ENGINE GOVERNOR
SIGNAL LIGHT
MAIN CONTROL UNIT
TRAIN ALARM BELL
ALARM
ENGINE COOLANT TEMP. SENSOR
MAGNETIC PICK-UP
FP/ES MODULE
TRAIN LINE
TRAIN LINE RECEPTACLE
DRAIN TEMP. SW.

SYSTEM LAYOUT

# DISCUSSION ON
# PRESENTATION BY G. LEVESQUE

R. BERGNER (Bombardier): My question is on the fuel economy during the summer months as opposed to the winter months. I presume it is solely related to the ambient conditions. It is easier to start the engine in the summer months when the ambient is high. Are there any other factors involving the high level of economy in the summer and the low level in the winter?

G. LEVESQUE: No. The ease of starting is quite independent of the ambient because the system regulates the engine temperature between 100° and 130° F. The engine would be shut off at 130° F. and re-started when it cools down to 100°F.

P.A. LAROSE (CANAC): A few years ago a railway supply company came up with fuel saver devices for road engines. Is it fair to say that in your case the difference is basically that you shut off the engine as opposed to turning it down to idle?

G. LEVESQUE: Yes. The previous devices would just put the engine to idle. In our case we shut them down. We re-start them as required.

P.A. LAROSE: Do you have a quantitative estimate of the marginal saving in fuel through shutting down the engine instead of letting the engine idle?

G. LEVESQUE: The estimated fuel saving on the QSNL for a road unit, including savings shutting down the engine, will be in the order of 10%. This 10% is the overall figure for a year period. I have no precise percentage for any particular case. The one on this graph refers to road operation, - the curve on top. It is the cost of fuel per car with four locomotives and you could take the same train and using only three locomotives you are going to save 8%. The fact is that most of the time they are going to use three locomotives as the fourth one is only there for the difficult portion of the line.

P.A. LAROSE: To compare the fourth locomotive idling instead of being shut down, I would suppose that this new curve would closely follow the lower one that you have. It would be lower than the four units working.

G. LEVESQUE: Well certainly the lower one and it will probably be significantly lower.

P.A. LAROSE: In this quantitative estimate of fuel saved, have you in any way changed the engineman's operating habits? Do they still use power braking?

G. LEVESQUE: There is no change in the handling of the train. There has been some concern for train handling when power is recalled by the engineman, but that can be overcome.

P.A. LAROSE: The reason I am asking this last part of my question is that two years ago there was a paper by Skene and Bigelow and another author. They reached the conclusion that much of the claimed fuel saving from these devices was due to the excess energy being used. When an engineman is given "too much" horsepower, much of it will be used up in power braking. When you turn the excess power off, you really give the engineman less power to waste; in other words, the laws of energy conservation are maintained. The authors' conclusion was that equal benefits would be achieved by proper management of the power available during the cruise cycle of the engine.

G. LEVESQUE: You can achieve some savings by better management of the available power.

C. GANNET (U.S. DOT): On a descending grade in road service, does the unit come back on for dynamic braking?

G. LEVESQUE: It is up to the engineman to decide how many locomotives he requires for dynamic braking. A locomotive unit must be working to be available for dynamic braking. The engineman must start a unit before he can use it for dynamic braking.

# A FACILITY FOR MEDIUM SPEED DIESEL ENGINE RESEARCH AND DEVELOPMENT

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## ABSTRACT

This report is an overview of the Bombardier Single Cylinder Research Engine (BSCRE) programme and its evolution to a full-capability research facility for medium speed diesel engines suitable for locomotives, ships and generators.

The program, which started in 1982, has progressed to the final stages of Phase III which covers the calibration and qualification of the 1-251 and 1-B2400 BSCRE versions.

A description of the engines and test cells is given. Also some of the R&D capabilities of the facility, including the yet to be completed fuels and lube analysis lab and the turbocharger development test cell, are highlighted in the paper.

# A FACILITY FOR MEDIUM SPEED DIESEL ENGINE RESEARCH AND DEVELOPMENT

## INTRODUCTION

### BACKGROUND

The economics of the use a single cylinder engine in research and development are well known. The R&D group of Bombardier's Rail and Diesel Products Division (RDPD) were involved in three programmes which justified the need for such an engine.

1- Up grading of the 251 engine
2- Design and development of the B2400
3- Alternate fuels testing

After a survey of available single cylinder engines it was concluded that none that could be purchased, represented a locomotive medium speed diesel engine. Therefore a proposal for funding assistance in the design of a single cylinder engine based on the Bombardier/Alco 251 engine and a complimentary test cell. This proposal was accepted and a contract was awarded with Bombardier on a cost shearing basis in 1982.

## DISCUSSION

Phase I: Here the scope of work included the design of a single cylinder engine and a stan-alone test cell. The five fundamental parameters which were establishes for the engine were:

1- Representation
The engine had to be representative of the Bombardier engines. The current Alco 251 series of which there are approximately three thousand in service and the newly designed B2400 are both turbocharged.

2- Durability
A research tool, that is, it would be capable of operating outside the current and near future production, higher firing pressure together with higher and/or lower RPM.

3- Flexibility
A necessary requirement which must be satisfied if various research studies are to be performed without major modifications to the engine, combustion studies and lube oil studies for example.

4- Accessibility
Components must be accessible without the need to remove unrelated items, also the ease of instrumentation had to be considered.

5- Maintainability
Maximum use of off-the-shelf components including engine family standard parts and maintenance hardware.

With the above, the design philosophy and literature search of single cylinder engines, plus a projection of what future capabilities would be required; a functional specification (given below) and conceptual layout was made.

The resulting design incorporated a common bed plate bottom end assembly, a 251 upper end assembly and a B2400 upper end assembly therefore meeting the requirements of both the Bombardier engine families. See Fig. I.

## Engine Component Design Features

It should be stated first that all components making up the valve trains and power assemblies of the two BSCRE versions are standard components of the 251 and B2400 engine series.

Bottom end assembly:

The lower part of the engine is of welded steel bed plate construction incorporating cast steel cross webs which support the crankshaft in three tri-metal bearings. Below the crankshaft are the primary and secondary balance shafts which are driven through a gear train by the crankshaft.

## FUNCTIONAL AND DESIGN SPECIFICATIONS
## (BASIC)

### Application

- Research into future fuels combustion for medium speed diesel engines.
- Engine component development and assessment.
- Lube oil research classification, and screening.

### Design Data

| Engine configuration | 251 | B2400 |
|---|---|---|
| Bore & stroke | 229mm x 267mm | 240mm z 270mm |
| Displacement | 11.00 L | 12.2 L |
| IMEP (max) | 23.0 bar | 25.0 bar |
| Pmax | 145.0 bar | 175.0 bar |
| Crankshaft journal dia. | 216mm | 240mm |
| Crankpin dia. | 152.4mm | 190mm |
| **Rated Speeds** | | |
| RPM | 1200 | 1200 |
| Piston speed | 10.66m/s | 10.80m/s |
| Idle | 200 | 200 |
| Overspeed | 10% (30% without failure) | |
| **Fuel Injection** | | |
| Rate (No.2D) | 1530 mm3/inj. | 1838mm3/inj. |

## Functional Data

### Overspeed Trip Device

Mechanical - with manual actuator

### Governing

Electronic

### Lubrication

Remote pump, dry sump - Optional
Oil: SAE 30, 40, multigrade
Flow rate: to suit

### Fuel

Distillates
Canadian middle distillates

### Starting Equipment

Electric dynamometer (with motoring capability-Optional)
or
Air start

### Cooling System

Jacket water pump - remote driven
Flow rate: to suit

### Balancing

Primary balance shaft gear
Secondary balance shaft
Crankshaft counter weights
(unbalanced forces and couple to be minimized)

### Manufacturing

Existing tooling and machines to be used where possible
Maximum use to be made of off the shelf components

### Upper End Components

Cylinder head assembly
Piston/rod assembly
Fuel pump support assembly
Valve train components
Camshafts & gear train

## Bottom End Components

Crankshaft
Balance shafts and gear train

The bed plate type of crankshaft support deviates from the multi-cylinder versions of the two engine series which are underslung. However the advantages were considerable, of which some were, being able to use a common design for both engines, ease of inspection of crankshaft, main bearings, and balancing system (Fig 1).

The cast steel cross ribs which carry the three main bearings, one close to the flywheel and the other two either side of the crankpin, were designed with the aid of finite element analysis (F.E.A.) to optimize the geometrical shape for minimum weight and firing load distribution.

The balancing system consists of two counter-rotating primary and two counter-rotating secondary shafts to which, are bolted eccentric masses. These shafts are driven through a gear train from the crankshaft at the free-end of the engine.

## Upper End Assembly:

The fabricated cylinder block is of welded steel construction incorporating the cylinder liner, adjustable camshaft which actuates the fuel pump and valve push rods and carries on the flywheel-end a train of surface hardened gears to drive the camshaft. Access doors and clearance holes allow for adjustment or removal of the camshaft. Individual upper and lower liner cooling water inlets are provided. This feature will be necessary in the study of off-spec fuels. The cylinder liner is sealed at the bottom by two elastometric "O" rings.

## Crankshaft and bearings:

An objective of the design was representation of the Bombardier engines and making use of as many components as possible which were readily available. Except for a change in stroke and larger crankshaft diameter, the crankshafts are similar.

The main and big end shell bearings are of the high load carrying, tri-metal type, designed to be compatible with the nitrided crankshaft.

## Lubricating System:

A wet sump system is employed with oil circulation by a pump driven independently of the engine, which allows for easy conversion to a dry sump system. Four separate lubricating oil supplies are provided which are externally connected to a common manifold, which can be regulated for pressure and flow rate control.

1- Cylinder head
2- Camshaft and drive gears
3- Crankshaft bearings
4- Balance shafts.

Some work was undertaken aimed essentially at examining the feasibility of four separate oil circuits which would be required in the study of the crankcase oils with different additive packages. The lube oil evaluation (LOE) version of the BSCRE will have this feature.

In the basic BSCRE design the oil drains to a oil sump which is designed with sloping sides and bottom, which will prevent retention of the oil under test and promote maximum circulation if a dry sump system is used.

## Camshaft

Knowing that, to obtain optimum performance in both combustion and alternate fuel studies would require a variety of intake and exhaust event durations, the camshaft was designed with adjustable intake and exhaust cam lobes for timing and dwell with constant opening and closing ramps. The fuel cam lobe is adjustable in timing only and has a design capacity of 2,000 bar in order to reliably produce the high injection pressures for high BMEP work.

Removal of block side covers gives direct access to the camshafts which after release of the locking devices can be rotated to the required position.

## Coolant Water System:

The pump which circulates the coolant is remotely located and independently driven. The system is pressurized. Coolant enters the engine at the lower part of the block, travels up and around the outside of the cylinder liner, providing bore cooling, then passing to the cylinder head, circulating through the cooling passages around the valve seat and exiting at the top side of the exhaust port.

### Instrumentation:

Signal generators and pickups for crankshaft and cam position indicators and triggering can be mounted on the free-end of the engine. Removal of cover plates on the front gearcase allows the fitting of two instruments driven at engine speed and two instruments driven at twice engine speed by the balance shafts.

### Engine Protection:

An electric governor was chosen for two reasons. First, compatibility with computer engine management systems and secondly, fast response and sensitivity to engine speed. A magnetic pickup is mounted in proximity to the flywheel teeth.

Two fail-safe modes are built into the system. If d.c. power to the governor is interrupted or the speed reference signal is lost the output shaft returns to the minimum fuel position. This feature prevents sudden stopping of the engine under load avoiding engine seizure or the ruining of the test.

Overspeed protection is provided by a mechanical device fitted to one of the free-end rotating shafts.

### TEST FACILITY

A prerequisite of this task was to first establish the requirements of the facility that would satisfy medium speed diesel engine research. The class of engine represented is turbocharged, therefore, it is necessary to provide a separate air supply to the engine and a variable exhaust restrictor, simulating turbine back pressure.

The engine power output is absorbed by a suitable dynamometer matched to the torque curve of the engine.

The characteristics of all the supporting equipment were defined, maximum vibration and noise levels established. Calculations to determine heat transfer requirements, flow rates and all other parameters were performed during the functional specification activity.

The key objective was to utilize available space for equipment installation while maintaining accessibility for maintenance purposes, such that a building of minimum size and therefore minimum cost would be the result.

## Phase I Addendum: Engine Manufacture

Changes in our in-house engineering capability made it possible to perform all force saving all funds that were allocated to outside computer time shearing. A cost analysis at the end of the design work showed that there was a surplus of funds and that it was possible to cover the major portion of the engine manufacturing coast. his estimate was done realizing that pistons, liners, con-rods, valve gear, cylinder heads and fuel injection equipment were on the shelf.

Before the start of manufacturing it was found necessary to convert the design drawings to shop drawings which took considerable unforeseen engineering hours. At this point also, a decision was made to fabricate both engines because of similarity of the fabrications.

It can be seen from the cost breakdown below which shows the considerable discrepancy between the estimated and actual costs when totalled approximately two years later. Some of the increase was due to labor and overhead rate changes. The most significant contributors, however, were the labor or time intensive tasks namely engineering, fabrication and assembling.

| | TASK | ESTIMATE | ACTUAL |
|---|---|---|---|
| 1- | Project management | 7,000. | 17,000. |
| 2- | Engineering | 16,500. | 112,300. |
| 3- | Material | 58,000. | 98,600 |
| 4- | Tooling | 4,000. | 23,000. |
| 5- | Fabrication | 18,500. | 114,000. |
| 6- | Assembling | 4,000. | 46,500. |
| | | $108,000. | $411,600 |
| | Per engine | 54,000. | $205,800 |

Knowing that a fixed percentage of the original estimate of $108,000 would be covered by TDC funding Bombardier recognized the significants of having the single cylinder version of the B2400 multi, which was entering the manufacturing stage, in advance and the short term benefits. Therefore they would absorb the additional costs.

From an overall point of view no major difficulties were encountered with either the 251 or B2400 versions during manufacture. The concept of having two engine designs with a common bottom-end has proven to be a viable approach. The flexibility of the bed plate design allows for numerous bore/stroke combinations.

## Phase II: Construction and Installation

The design approach taken in Phase I was to prepare a basic engine design and a typical test facility with several options in equipment and methods of supporting the engine.

Phase II of the BSCRE Programme covered the establishment of two test cells, one for each engine. At that time our existing Engine R&D test center consisted of two modern multi-cylinder cells,work shops, stores, electronic and fuel injection repair rooms. It was this environment that defined the location and the parameters to achieve compatibility and system integration of the two new single cylinder test cells, causing the modification of the auxiliary supporting systems to suit. The description follows:

### Building & Construction

Since the existing test facility could not house the two single cylinder engines, the decision was made to add an extension to the test center. The chosen building configuration contained three rooms, two cells and a common control area for both cells and electrical motor control center (MCC). In order to dissipate the damaging vibratory forces which are inherent in single cylinder engines the engine foundation was designed to absorb the major portion of this energy. Isolation of the block from the building is achieved by a flexible membrane around and below the reinforced concrete block on a bed of compacted sand.

The test cell is equipped with all the necessary services including an overhead crane. Allowances were made to accommodate future equipment or changes due to research study requirements.

The location of the test cells with respect to the existing storage and workshop areas eliminated the necessity of providing additional space to satisfy these functions.

### Facility Mechanical Features

The layout of the equipment within each cell is a mirror image of the other. In order to maximize the use of the available space, all auxiliary equipment except for air-start and dynamometer supply piping are located on one wall of the cell. The intent was to free-up as much floor space as possible therefore a support structure and mounting system was devised to allow the tanks and reservoirs to be located off the floor.

The auxiliary systems supply piping, i.e. fuel, water, and air, enters the cell at the upper corner above the equipment rack then branches to each system. As shown in Fig. 1 & 2 the three fluid supply tanks from right to left, are the jacket water holding 455 liters, fuel oil 455 liters and the lube oil with a capacity of 680 liters. Situated between the tanks are two heat exchangers which preheat the jacket water and lube oil as required. Adjacent to each system arrangement the manual circuit breakers and stop/start switches are located at the lower level of the equipment rack with manual normally open or closed valves, flow measuring devices and indicators. At the center of this lower apparatus cluster is a fuel measuring device. This fuel measuring device was designed and built by Bombardier Engine Lab. based on an old and well known gravimetric method but incorporating today's microprocessor technology.

As can be seen the basic layout consists of three main equipment groupings, water, fuel, and lube oil terminating at floor level with all related controls and instrumentation within these groups. This vertical arrangement facilitates circuit tracing, trouble shooting, and maintenance (Fig. 2).

Outlets from three systems are at floor level and are routed beneath the engine maintenance platform to the engine.

Intake and Exhaust

The apparatus which is required to simulate turbocharging is part of the intake charge air and exhaust systems.

A remote compressor supplies air which passes through a series of heaters to a plenum changer, thus smoothing the pulsations to an acceptable level. The capacity of the chamber is critical to the multi-cylinder representation.

The exhaust system consists of an expansion chamber, a fixed orifice which simulates the characteristics of a turbocharger turbine, a variable gate valve, and finally an exhaust silencer. The variable valve controls the pressure setting which would be representative of the multi-cylinder engine manifold configuration.

## Engine and Dynamometer

In the center of the cell is the skid mounted engine and dynamometer. The engine is connected to the hydraulic dynamometer which is capable of absorbing four hundred horsepower. Situated around the assembly is a removable non-slip platform to facilitate engine maintenance.

## Safety

For reasons of safety and the protection of working personnel, a free standing guard covers the flywheel. Fusible links and deadman valves are incorporated in the fuel circuits which will stop fuel flow in case of fire. Also the cell floor is below level of the MCC/control room floor thus containing any fuel spillage.

## Auxiliary Systems

An electric motordriven water pump circulates water through the engine jacket and heat exchanger (tube side). The flow through the engine jacket is measured by an electromagnetic flow meter. Temperature setpoint by a temperature control valve.

The system includes a heater (thermostatically controlled) in the recovery tank that heats and circulates the jacket water to air cold starting.

To simulate water flow variation proportional to the engine speed in comparison with a multi-cylinder engine, a remote controlled throtting valve is installed on the engine jacket water system.

## Lubricating oil System

An electric motor driven pump draws oil from the sump and passes it through a magnetic filter, heat exchanger, and filter then into the engine main bearings.

A thermostatic controlled heater is installed in the oil recovery tank, for heating the lube oil to aid starting.

To simulate multi-cylinder engine oil flow variation proportional to the engine speed of an engine driven pump, a motorized valve with bypass is incorporated lube oil system.

### Fuel Oil System

Fuel is pumped to the day tank from the main storage tank. The level of the day tank is controlled

by a level switch. Fuel flows by gravity into a small weighing tank with the fuel flow measuring device when the solenoid valve is energized by the fuel.

Fuel is drawn from the fuel weigher by the engine booster pump; through a filter to the engine fuel pump.

### Engine/Dynamometer - Load and Speed Control

The speed of the engine is controlled by an electronic engine governor, the set-point for which is adjusted by a servo motor. The governor will adjust the fuel pump rack to suit the load on the engine and to maintain a constant engine speed.

The load on the engine is controlled and measured by the dynamometer which is maintained by controlling the amount of water in the casing, determined by the position of the outlet valve.

### Phase III

The objective of the current Phase is to complete the support equipment installation, establish a performance baseline for both engines, correlate with the multi-cylinder engine fuel testing, and complete the design stage of the turbocharger test rig.

At this time only two sub-tasks remain to be completed. Primarily the alternative fuels correlation with the fuels tested for DND on on the 12 cylinder 251 engine. The 1-B2400 was used to define the basic fuel and timing configuration prior to starting-up the B2400 multi. The 1-251 was used to evaluate the 251 + engine components before release for field testing.

In addition, two BSCRE's were sold one to NRC and the other to AAR (Washington DC) for installation at Southwest Research Institute (SWRI).

Turbocharger influence; the inclusion of a task in the single cylinder program was due to the following. The parent medium speed engines are turbocharged and single cylinder engine cannot support a turbo. The BSCRE with its simulated turbocharged air system can produce optimum boost air values which are outside the capability of the turbo being used on the multi-cylinder. These values can be transferred to test rig and adjustments made under controlled conditions until they are achieved. The excess air from the turbo-rig is piped to the air supply reservoir of the test cells.

With the capability to perform both fuel and lube oil tests it was logical step to being able to analyze these fluids, therefore need for the F/L analysis lab was justified. The three sections which make-up the F/L lab are; fuel handling, fuel blending and analysis.

## PHASE IV

A proposal for continued funding consideration was written and submitted to TDC. The emphasis on alternative fuels is no longer there, and also the Bombardier Engine Research and Development Resources have expanded in expertise and capability.

The work which is planned in Phase IV is the completion of the turbocharger influence task, perform some additional engine qualification work and coordination with the two existing BSCRE owners NRC and AAR and most important expand the capability of the BSCRE, that is, the development of the lube oil evaluation (LOE) version. The current trend in lubricating oils is toward multi-grade oils or some times called fuel efficient oils. Conflicting reports have been made on the benefits of using these products in heavy duty high speed and medium speed engines. The argument which has been raised in recent published papers is that lubrication might be diminished in some areas of the engine.

The BSCRE - LOE version with its isolated four (4) lube oil circuits will allow for four (4) different types of oil to be used at the same time.

| | | |
|---|---|---|
| 1. | Power train: | Crankshaft and connecting rod bearings, piston assembly |
| 2. | Camshaft: | Cams and valve train |
| 3. | Gears: | Camshaft and balance shaft |
| 4. | Balance shafts: | Primary and secondary. |

This feature will be very instrumental in resolving and classifying of base oils and multi-grade formulations.

## SUMMARY

The recognition of the Bombardier Single Cylinder Research Engine by NRC, SWRI, Ricardo, all noted diesel engine R&D establishments, as the only research engine base on a currently operating engine, and capable of producing the high loads of todays turbocharged engines was demonstrated. It is also visualized by the research community that this engine will be the replacement for the EMD 567 twin as the screening and evaluation device for heavy duty and railroad oils.

A planned coordinated research program between NRC, SWRI, and Bombardier R&D addressing ceramic components, staged and pilot injection, low cetane and off-spec fuels have already been outlined.

In conclusion the BSCRE Program has progressed from a need for an economical method of testing alternative fuels and design evaluation of engine components to a totally integrated facility for medium speed diesel engine research and development; plus the acceptance of the BSCRE as a unique research tool.

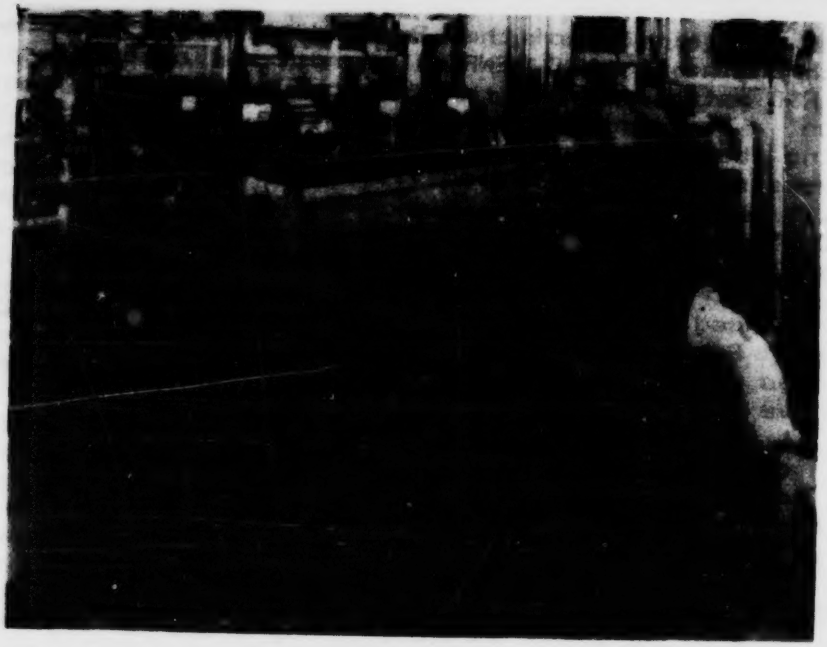

FIGURE 1 – SINGLE CYLINDER ENGINE BED PLATE BOTTOM END
(SHOWING BALANCE SHAFTS DRIVE ARRANGEMENT)

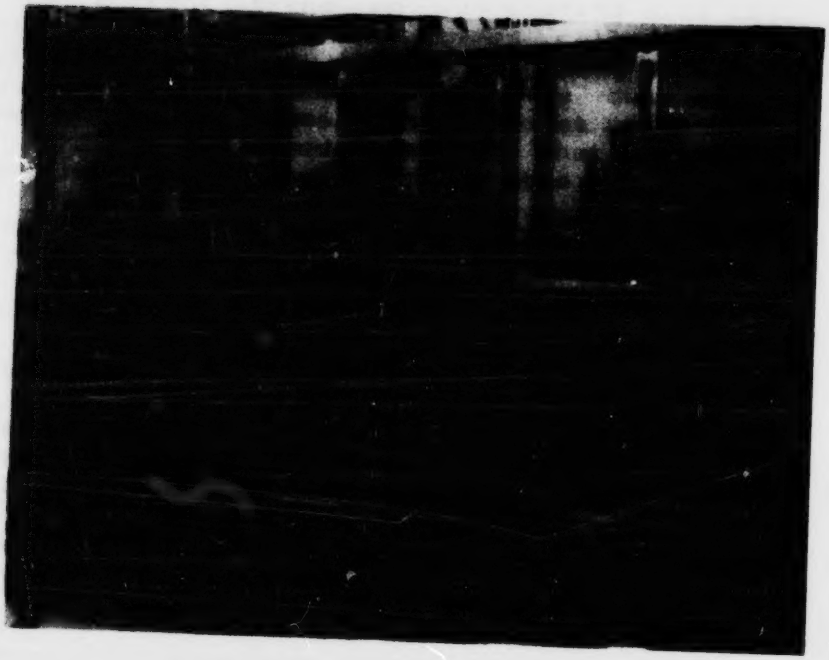

FIGURE 2 – AUXILIARY EQUIPMENT
(SHOWING WATER, FUEL AND OIL MODULAR LAYOUT)

FIGURE 3 — I-251 BSCRE · CELL No. 4

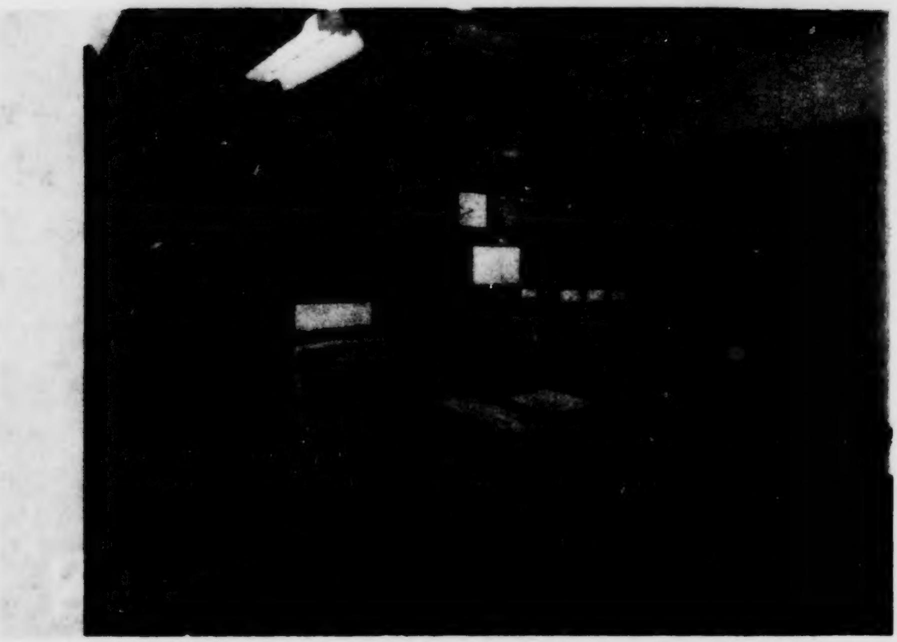

FIGURE 4 — I-251 TEST CELL No. 4
CONTROL CONSOLE AND COMPUTER DATA AQUISITION EQUIPMENT

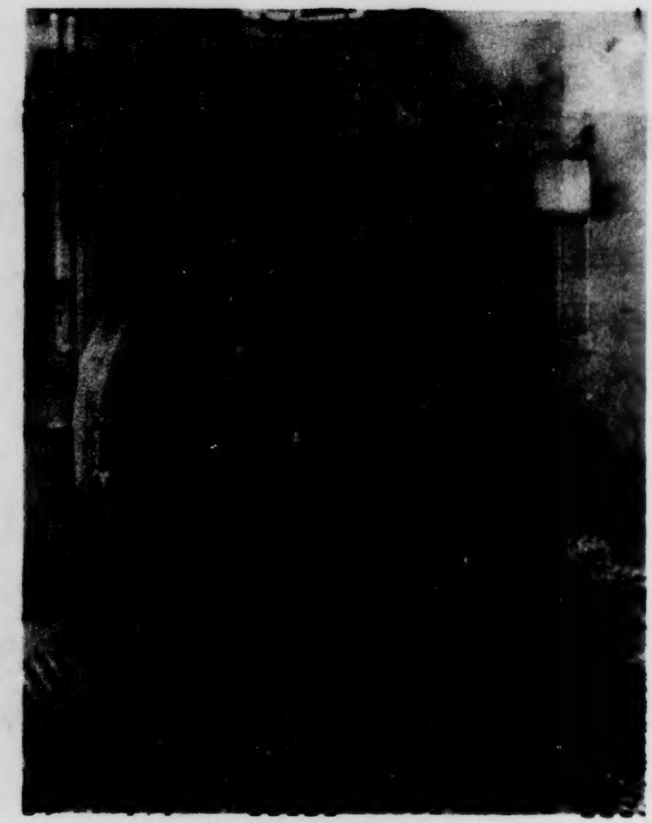

FIGURE 5 — I-B2400 BSCRE - CELL No. 5

FIGURE 6 — I-B2400 TEST CELL No. 5
CONTROL CONSOLE AND COMPUTER DATA AQUISITION EQUIPMENT

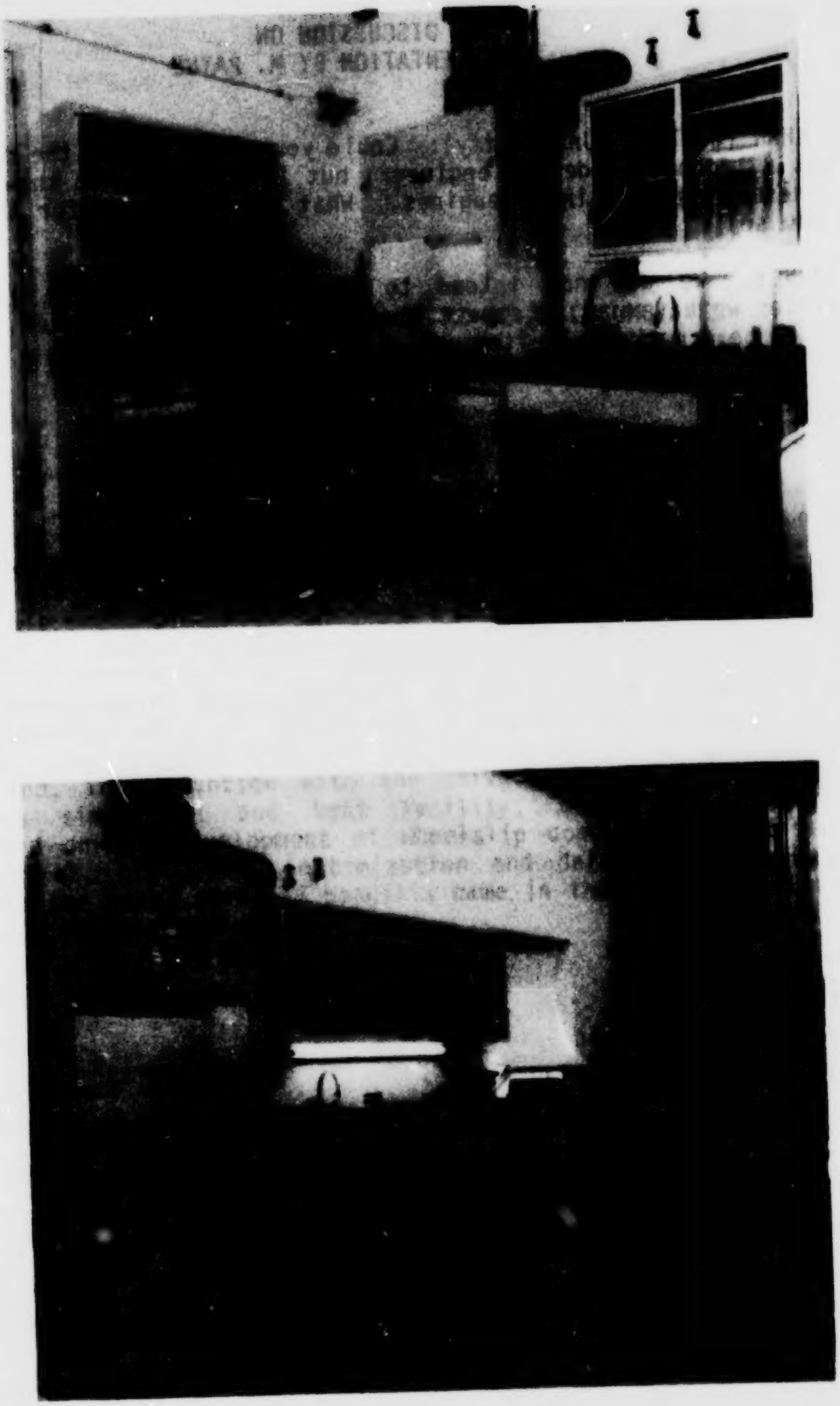

FIGURE 7 & 8
PARTIAL VIEWS - FUELS AND LUBE ANALYSIS LABORATORY

## DISCUSSION ON
## PRESENTATION BY M. PAYNE

A.M. KHAN (Carleton University): Could you elaborate on the market side? I am not a locomotive design engineer, but I would like to know where you can use these single cylinder engines. What is the market for them? How many can you sell?

M. PAYNE: We did not intend to sell any at all, but judging by the inquiries we have had, I expect that we would sell about ten. It was never meant to be a marketable item.

# MICROPROCESSOR CONTROL OF AC-DC-AC LOCOMOTIVES

M.J.Nixon
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## ABSTRACT

With the inclusion of MICAS computers in the program to retrofit BBC three phase AC traction on a CP locomotive, a project was developed to optimize their use. The project involved the development of a systems laboratory facility and, in conjuntion with the University of Toronto, a real time interactive simulation and test facility, RIST. The project then concentrated on the development of wheelslip control software as well as engine control, protection, optimization and data logging concepts. In addition to the work, spin-off benefits came in the form of definitions for future hardware development.

# MICROPROCESSOR CONTROL OF AC-DC-AC LOCOMOTIVES

Early in the definition of the three phase AC locomotive project, a program involving the retrofit of an existing CP Rail locomotive with BBC 3 phase AC traction, it was decided to incorporate a MICAS computer into the locomotive control. The reason for taking this approach was to reduce the size, weight, cost and complexity of the electronics required for the control of an AC-DC-AC locomotive. Additionally, changes in the control functioning could be more readily accomplished with computer control than with hardwired control. In order to provide maximum capacity and flexibility two BBC "MICAS" computers were used.

The first computer was supplied with software to permit it to control the detailed overlay functions of the inverter control. The second computer was supplied with a basic software package to provide a link between the conventional locomotive controls and the electronics. The functioning of this locomotive control was conventional in all respects.

BBC realized, however, that the control possibilities of the computer far exceeded the basic interface functions.

The potential benefits to the locomotive operator included:

- reduced fuel consumption
- improved adhesion utilization
- better train handling
- reduced wheel damage
- simplified diagnostics
- ready interface to other locomotive controls and system.

In order to achieve these possibilities, however, would involve extensive research and testing.

Thus a proposal was presented that became the project titled "Microprocessor Control of Propulsion Electronics for an AC Diesel Electric Freight Locomotive".

Due to the University of Toronto's experience in the area of microprocessor systems and software development, they were assigned a portion of the project. They possessed the personnel and laboratory resources necessary to support this endeavor. Equipment and facilities were established both at the University of Toronto and BBC locations in order to provide a systems laboratory.

At BBC, a system test rig consisting of a complete locomotive control with two computers, an inverter and traction motor was established. This facility serves as a system familiarization unit as well as providing the ability to effect the software integration into an exact copy of the locomotive system. Within this facility, certain limited functional tests can be executed, and it provides an environment for software observation and preparation for locomotive application.

This facility, however, cannot simulate the total plant environment of the locomotive. The locomotive environment is composed of the prime mover and its operational characteristics. The transmission system components such as the motors and wheelset dynamics, the wheel rail dynamics and the train dynamics. The use of a locomotive for the development testing was impractical due to the cost, time and logistic problems involved. The only practical solution was the development of a simulated environment for software operational evaluation. The development of this facility was assigned to the University of Toronto, who proceeded to develop a Real time Interactive Simulation and Test system, called RIST for short.

RIST had to interface to the control computer in the same way, including signal type and characteristics, as the real locomotive. Additionally, it had to model and respond in real time and in the same manner as the real locomotive, track and train dynamics system would.

The RIST system was physically built using two additional computers. The core computer was a VME 68000 computer system. This system was connected to the MICAS computer through analog input output ports as well as digital i/o parts which simulated all locomotive interface connections. The physical variables such as locomotive controller inputs and interactive dynamics were input to the RIST system through another group of i/o channels which permitted the introduction of variables into the simulator with a locomotive consol. The control of the RIST system was effected through a separate serial terminal.

Data to permit evaluation of the operation of the software was output via a parallel port to a University of Toronto 6809 based single board computer. This computer formatted and prepared the data for display on an oscilloscope as a moving multiple plot similar to a paper chart recorder. The data displayed and its format were controlled through a terminal connected to the 6809 computer.

For the RIST system to perform useful work required the development of a modular software system consisting of modules for effecting the simulation of the various aspects of the vehicle operation.

The modules for the simulation of the locomotive system are the programs DLOCO, ELOCO, MLOCO, TLOCO and LOCO. The program DLOCO simulates the diesel engine. The program ELOCO simulates the traction command control. The program MLOCO simulates the electric drive with the inverter and the wheel-rail contact. The program TLOCO simulates the train. The program LOCO integrates all these modules and the program IOLOCO to the RIST system. All the modules with the term "LOCO" run on the VME computer. The programs are written in an extended version of the PASCAL programming language, which is available for the microprocessor development system used in the project.

The modules for the interfacing of the system are the programs IOLOCO, DATDIS2 and MDABL. These modules make the system interactive. They provide the software for the process interface to the MICAS microprocessor, for the plant operator or locomotive console interface and the communication interface. The communication interface has two parts, the VME computer terminal and the data display interface.

The program IOLOCO contains the software for the process interface to the MICAS microprocessor and the software for the "locomotive console" interface. It also contains the software for the interface to the VME computer terminal, which controls the simulation. A special routine IRQ3 in the program module IOLOCO provides the link to the data display system. The program module IOLOCO is the core of the software providing interactive simulation.

The program DATDIS2 runs on the SBC 6809. It is written in PASCAL. It contains the software for the display part of the communication interface. The DATDIS2 display program has the task of displaying data on the oscilloscope, which represent variables of the system simulation and the control algorithms executed in the VME and MICAS computers. The program acquires these data from the VME and MICAS computers by interrupting those computers. The display program uses the acquired data to update its data set and then writes a new graph on the oscilloscope screen.

On interrupt the VME computer executes the routine IRQ3 in the program module IOLOCO and provides one Byte of data at the parallel port, which is connected to the display computer. The MICAS computer works similarly, but it is connected through a serial port and a separate interrupt line to the display computer. The supporting software in the MICAS system is the program MADBL.

The program MADBL is a "MICAS block" designed and written in 8086 Assembler language. It provides an interrupt to the DATDIS2 program in the display computer. The data is supplied through the serial port used to monitor the MICAS operation.

With the development and testing of RIST system complete, the activity turned to the development of application software for the MICAS. After review of possible options, four areas were addressed in this phase.

First) Wheelslip control
Second) Data acquisition and monitoring
Third) Engine overload protection
Fourth) Fuel saving through control

For wheelslip control, the AC transmission system possesses the unique capability of permitting very precise control of wheel speed independent of torque. In order to capitalize on this fact, two elements are required. The first is the availability of an absolute ground speed reference, which is beyond the scope of this project; and a tractive effort optimizing routine. A detailed analysis and simulation of the present control and several other options were undertaken. The result of the effort was the development of a control algorithm which continually seeks the peak tractive effort level. In simulation, this technique shows excellent improvement over current control strategies. The research has also defined areas which will require additional work to permit practical utilization. For the system to be effective, it must have data relevant to a resolution of better than 0.4% which defines two areas requiring additional development. The first is the need for a precise reliable ground speed reference, and the second is the need for higher resolution in the analogue processing of the ground and wheel speed signals. These aspects are currently under investigation.

The second area of development is data acquisition and monitoring. Analysis of the MICAS computer architecture reveals that it is not optimum for the tasks of long term data storage, display and analysis. The MICAS computer was designed to be an easily programmed control computer capable of both digital and analog control functions in real time. It incorporates an operating system called MICAS language. This language consists of standard subroutines or blocks which perform actions equivalent to electronic discrete circuits such as amplifiers, comparators, logic gates etc. A program is written as a list of functions or block calls. The interconnections between the various ports of the devices are given memory addresses. Ports with common addresses are connected together as they would be in a physical circuit. Unlike a physical circuit, however, changes can be quickly made by changing the program listing. The program can be generated directly from a schematic diagram. To achieve these functions does not require large amounts of random access memory, battery backed memory or direct visual display. Rather than modify the MICAS architecture, which is beyond the scope of this project, an alternative approach was developed. This took the form of the development of a programming block, MADBL, previously mentioned, which can be inserted into normal control programs and permits the internal working data of the MICAS to be available to an external data logging and analysis system. This routine was developed, integrated into the MICAS, tested on the RIST system, and proved operational.

The third area investigated was engine overload protection. This involved the analysis and development of routines to monitor and stabilize the engine via the generated load. While the advantages to be gained with the current governors are limited, the potential for their future use in electronic governing techniques are under study.

The fourth area, of fuel savings through control strategy, was investigated through two avenues, on a single locomotive and on a train control basis.

On the individual locomotive, optimum savings are obtained by continually matching the engine to the lowest specific fuel consumption point. As with the overload control, the advantages can only be realized through direct electronic governing.

Train control requires precise data on train make-up, route position, route characteristics and speed restrictions in order to complete the most efficient train handling procedure. While the capability of effecting this computation exists, the infrastructure to supply the external data does not. In this area of multi-unit train control therefore, no real advantages can be realized unless an external infrastructure such as that proposed by the Advanced Train Control System project, comes into being.

At the present time, we are evaluating the software as to which areas could be incorporated into the existing locomotive and the logistics required. Additionally, in other development work being done by BBC, the limiting factors of the current MICAS design are being eliminated and new concepts are being incorporated into advanced MICAS designs partly in response to the information developed in this study.

While some of the original objectives may not be as directly obtainable as hoped for, there have been gains not envisioned in the original project concept, such as in the area of computer development definition. We now have the capability to model and test control computers in a highly efficient environment at a fraction of the cost and time of vehicle testing. In the area of adhesion control, the work to date shows great potential for systems improvement.

In conclusion, the net result of the project will be improved control technology which benefits not only the product marketability but provide the users with a more profitable locomotive.

## DISCUSSION ON
## PRESENTATION BY M. NIXON

W. SERGEANT (CANAC): In my mind the locomotive environment means dust, oil, noise, vibrations and impact. I am not quite sure that is the environment you are trying to simulate. What is the current experience of microprocessors on board locomotives in that kind of an environment?

M. NIXON: We now have two MICAS computer systems running on CP 4744, and they have been in service now for over eight months in a North American locomotive environment. In Europe, there are several hundred microprocessor units running on rail vehicles, providing considerable experience with this equipment in actual rail application. The environment we were talking about simulating here was the actual control environment, the input-output control type of phenomena rather than the environmental phenomena.

# TRAIN DATA RECORDING SYSTEM

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and
R.J.Clark
Asst. Vice Pres. Digital Products & Technology
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(Transcribed from tape of Seminar Proceedings)

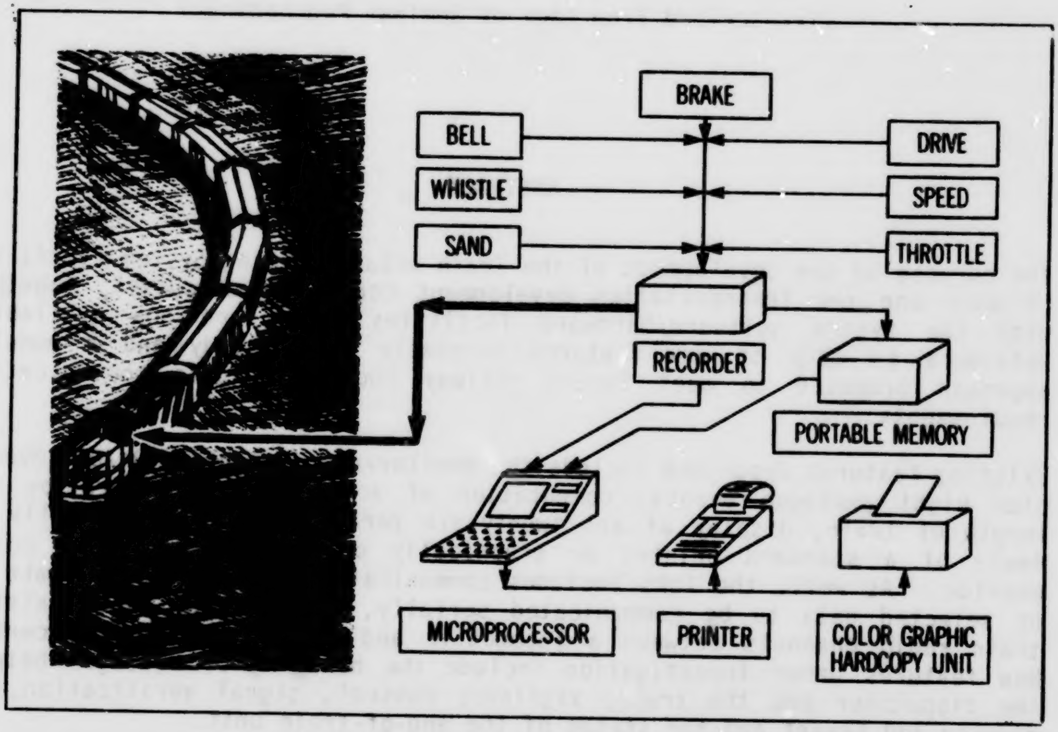
## ABSTRACT

The purpose of the development of the Train Data Recording System (TDRS) for CP Rail and the Transportation Development Centre is discussed, together with the system software/hardware facilities which are now available. Reference is made to new features currently under study and a modular approach proposed to meet future railway locomotive data communication requirements.

Existing features described include the monitoring of eighteen On/Off events plus eight analogue events, computation of acceleration/deceleration and length of train, display of all twenty-six parameters either digitally by means of a standard printer or graphically on a high resolution colour monitor. As well, the TDRS includes communications software to permit all or selected data to be communicated serially, for example, over existing train radio channels between a locomotive and a central dispatch centre. New features under investigation include the handling of messages between the dispatcher and the train, vigilance control, signal verification, cab display and keyset and the status of the end-of-train unit.

# TRAIN DATA RECORDING SYSTEM (TDRS)

A slide presentation


BRAKE
BELL
WHISTLE
SAND
DRIVE
SPEED
THROTTLE
RECORDER
PORTABLE MEMORY
MICROPROCESSOR
PRINTER
COLOR GRAPHIC HARDCOPY UNIT

G. Guevara: Thank you Mr. Chairman. Welcome to a presentation by MPB Technologies Inc. We are going to be talking about a train data recording system and sometimes, on some slides you will see only the abbreviation, "TDRS".

Well, I guess the first question is what does a train **data** recording system consist of? Well, it consists of a **Recorder** which fits inside the locomotive and attached to the recorder is a **Portable Memory** system, the recorder monitors the number of parameters in the locomotive including **bell, whistle, sounding, brake, speed, throttle.** All these are recorded in the portable memory system. The portable memory system is then brought to the play-back system which consists of a **Microprocessor.** It is a CRT-based system and there are two methods of having the data printed out. You can print it out using a **printer,** or you can get a **hard copy colour** representation of the data. You can also store the data on a mini **floppy disk.**

The purpose of the development of the train data recording system was:

1) To investigate the feasibility of a sophisticated on-board computer system for performing a variety of the train operation functions;

2) Development of software and hardware functions for an on-board train operation computer;

3) Test bed for monitoring and evaluation on-board railroad experiments (for example CN snowplow); and,

4) Evaluation of system components (sensors, connectors, packaging, radio links, cab displays, etc.).

**FEATURES DEVELOPED AND AVAILABLE** include:

- **Train Parameter Monitoring**
- **Measurement** and calculation of **Velocity** and **Acceleration**
- **Distance Recording**
- Short term (20 minute) **Crash Recording** at one second intervals
- Long term **Event Recording** (3 days)
- A simple and effective **facility** for **transporting** and **analyzing** train data **recordings**
- A train parameter **Cab Display** (speed, acceleration, brake pipe pressure at locomotive and at tail-end of train)
- **Message Interchange Control Procedure** for exchanging messages over a communication link.

**LIST OF PARAMETERS** monitored include:

- time (real and elapsed)
- time zones
- speed
- distance
- acceleration/deceleration
- length of train
- traction motor current

**LIST OF PARAMETERS (cont'd)**

- brake pipe pressure
- independent brake cylinder pressure
- equalizing reservoir pressure
- throttle level
- dynamic break
- locomotive initiated emergency
- lead unit power reduction
- sanding
- whistle
- vigilance
- leading
- trailing
- forward
- reverse
- wheel slip or creep
- bell.

**'LOCOTROL'** signals include:

- loss of continuity
- system power on
- MU mode
- independent mode
- 10 KHz clock failure
- penalty brake application
- auto brake release button.

## EXPERIMENTAL TRAIN PARAMETER CAB DISPLAY

```
DATE     28/09/85                  TRACTION MOTOR CURRENT       584 AMPS
TIME     12:07:35                  BRAKE PIPE PRESSURE           78 PSI
TIME ZONE  1                       INDEPENDENT BRAKE
SPEED   45 MPH                      CYLINDER PRESSURE             0 PSI
DISTANCE  625.78 MILES             EQUALIZING RESERVOIR          0 PSI
ACCEL/DECEL  -2 MPH/MIN            PRESSURE
LENGTH OF TRAIN 1500 FT

THROTTLE LEVEL        5            LOSS OF CONTINUITY            0
DYNAMIC BRAKE         0            (LOCOTROL)
LOCO INIT EMERG       0            SYSTEM POWER ON               0
LEAD UNIT PWR RED     0            (LOCOTROL)
SANDING               1            MU MODE (LOCOTROL)            0
WHISTLE               1            INDEPENDENT MODE              0
VIGILANCE             0            (LOCOTROL)
LEADING/TRAILING      1            10 KHz CLOCK FAILURE          0
FORWARD               1            (LOCOTROL)
REVERSE               0            PENALTY BRAKE APPLICATION     0
WHEEL SLIP, CREEP     1            (LOCOTROL)
BELL                  0            AUTO BRAKE RELEASE BUTTON     0
                                   (LOCOTROL)
```

In the upper left-hand corner we have the date, time zone, the speed, the distance the locomotive has travelled, whether it is accelerating or decelerating, and the length of train.

Below that is a list of all on/off signals. The upper right-hand corner shows all the analogue parameters that we are measuring, and below that are all the 'LOCOTROL' signals which are all on/off digital signals. If the signal is on it is shown as a "1# and if it is off, it is shown as a zero. The throttle level displays a code from zero to nine, corresponding to off plus positions 1 to 8, plus the "idle" position.

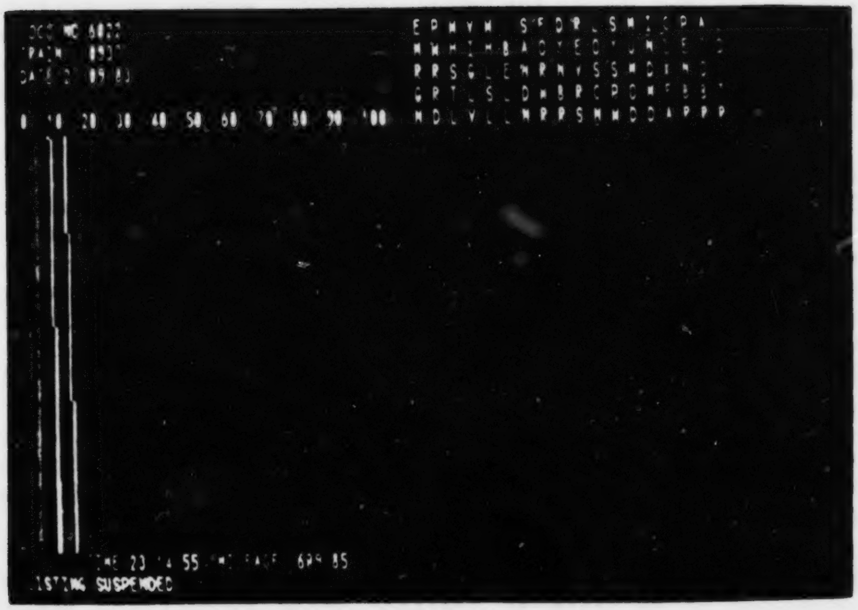
## TRAIN DATA RECORDING PRINTOUT

```
DATE  28/09/83  ZONE 2  TRAIN 0937  LOCO 6022  TRAK 5  STN 2320
                                 OP # 4123

 MILE      TIME      VL T AMPS BP IB  ER F R T P W B S C L V Q R U I K Y A

625.78   00:08:52  46 5  265 62 03  04
625.79   00:08:53  45 5  265 62 03  04
625.80   00:08:54  45 5  265 62 03  04
625.82   00:08:55  45 5  265 62 03  04
625.83   00:08:56  44 5  265 62 03  04
625.84   00:08:57  44 5  265 62 03  04
625.85   00:08:58  43 4  265 62 03  04
625.86   00:09:00  42 4  249 62 03  04
625.88   00:09:01  42 4  249 62 03  04
625.89   00:09:02  41 4  249 62 03  04
625.90   00:09:03  41 4  249 62 03  04
625.91   00:09:04  40 4  234 61 03  04
625.92   00:09:05  40 4  234 62 03  04
```

The data can be produced in two forms, one being an alpha-numeric printout from a standard printer, while the other is a 35 mm photographic output from a colour monitor using a slide reproduction process.

This is an example of the alpha-numeric printout. There is a header that is displayed at the top of each page which includes the **date**, the **time zone**, the **train**, **locomotive number**, track or route role, and the station number. The display on your left-hand side indicates the **mileage**, followed by **time**, and **velocity** (VL) and the **throttle** position (T), then **traction meter current** (AMPS) and then there is the **brake pipe pressure** (BP), the **independent brake pressure** (IB), and then the **equalizing reservoir pressure** (ER), all three values in pounds per square inch (psi).

So the first line indicates that the locomotive was going 46 miles an hour, the throttle was in position 5, and there were 265 Amps through the motor, the brake pipe pressure was 62 PSI and the time was 8 minutes past midnight and the locomotive had gone 625.78 miles and each line in the display is a subsequent recording.


0 10 20 30 40 50 60 70 80 90 100
LISTING SUSPENDED

COLOUR GRAPHIC DISPLAY

Note: B & W reproduction of colour photo produced from 35 mm colour slide taken off playback monitor screen has been used for economy purposes.

This is an example of the hard-copy colour printout (35 mm slide). The display is broken down into two sections. The left-hand section are all the analogue parameters and the right-hand section are all the digital parameters. If a signal is 'On', the digital signal is shown as a red color overlaid on the blue line. The analogue signals are all colour coded on the left-hand grid. The solid background blue indicates **speed**, the green indicates **brake pipe pressure** in pounds per square inch, the light blue indicates **independent brake pressure**. The red indicates **traction motor current**, and the pink indicates **equalizing reservoir pressure**. The **throttle** is in light blue. The scale is zero to 100 and the scale is divided by 10 for motor current. At the top of the display, the current shows forty. It is actually 400 Amps at that point and the throttle position is shown as 80, it is actually throttle position 8. The throttle is times 10 and the motor current is divided by 10 on that scale.

**Time** proceeds from the bottom of the display towards the top and there is a status line on the bottom which indicated the **time** and **mileage** at the very bottom of the display. So, if we go back in time by about 2 minutes (yellow vertical bar at 12), we see that at the very start of that display the throttle was in position 8, the speed of the locomotive was approximately 56 miles per hour, and the current through the motor was about 400 Amps. Now perhaps 15 seconds later, the locomotive engineer applied the brakes so there is about a 7 lbs per square inch drop in the brake pipe pressure (to 73 psi), but the speed did not change by very much. A little later on there was a further reduction in the brake pipe pressure of about 3 psi (to 70) as more braking effort was applied and the throttle was dropped to position 7 and then to position 6 as a further 3 psi brake pressure reduction (to 67) was applied.

The throttle reduction from position 8 to 7 to 6 was accompanied by a corresponding decrease in traction motor current (in red) from 400 to about 360 to perhaps 320 amps climbing slowly back up to about 400 amps briefly until the brakes were released and the throttle drapped down through 4-3-2-1 while the current dropped to less than 100 amps. Meanwhile, the speed of the freight train gradually decreased from a steady 56 miles per hour to about 23 mph in the space of about one minute and a half.

This is an example of our colour graphic printout. At this point in time, I would like to introduce you to Bob Clark who will give you the rest of the presentation.

R.J. CLARK: You will notice that Gerald gave a talk on two kinds of printouts, one of a detailed printout on hard copy using a standard printer the other one was a printout using category 2 CRT display graphically presented. The reason for the two was so that you could use the CRT display to very quickly analyze the data. You can scan through it very quickly to find out exactly where in the recording you would like to have a detailed printout.

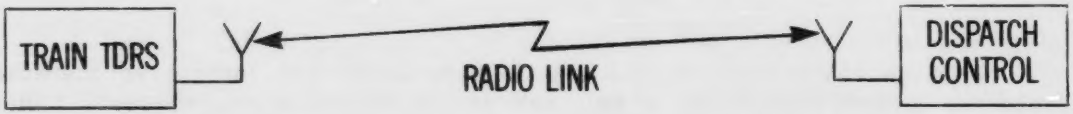
R.J. CLARK (cont'd)

From that point you are able to give the play back system an instruction to print a hard copy of it. So we not only developed recorders for this experiment, but we also developed a lot of software for analyzing the data.

**FEATURES UNDER DEVELOPMENT AND INVESTIGATION** include:

- Dispatching messages sending & receiving
- Monitoring tail-end
- Signal verification
- Vigilance control
- Cab display/printer/keyset
- Train control
- Modular operational TDRS.

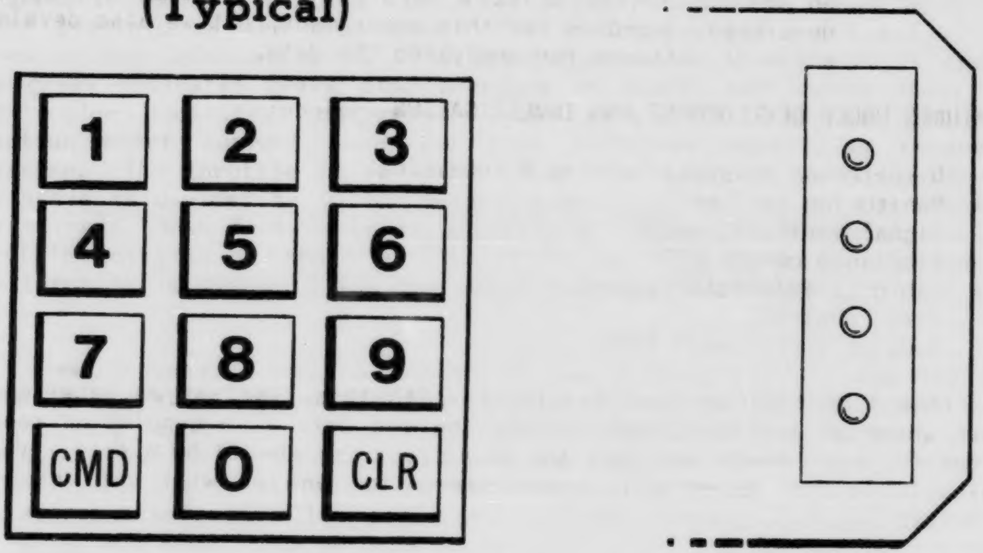
The TDRS that we have developed up to this time was an experimental unit where we put everything inside the one box. The conclusion reached after the experiments was that the basic recorder should be a small, rugged unit, built for essentially crash prevention and we will get into that a little later.



So, the first topic is **Message From the Dispatcher to Train.** These are under consideration currently in our investigation and these would include a **status request** from the dispatcher asking for certain parameters to be transmitted back to him so he can analyze how the train is performing. The next would be **train orders** and the last would be **train control.**

**Message from the Train back to the Dispatcher** that are being considered would be messages that would go back in response to status request from the dispatcher which would include **train identification, speed/-throttle position, acceleration/deceleration, brake pipe/tail-end pressure, signal** and **vigilance status,** and **location** within a block.

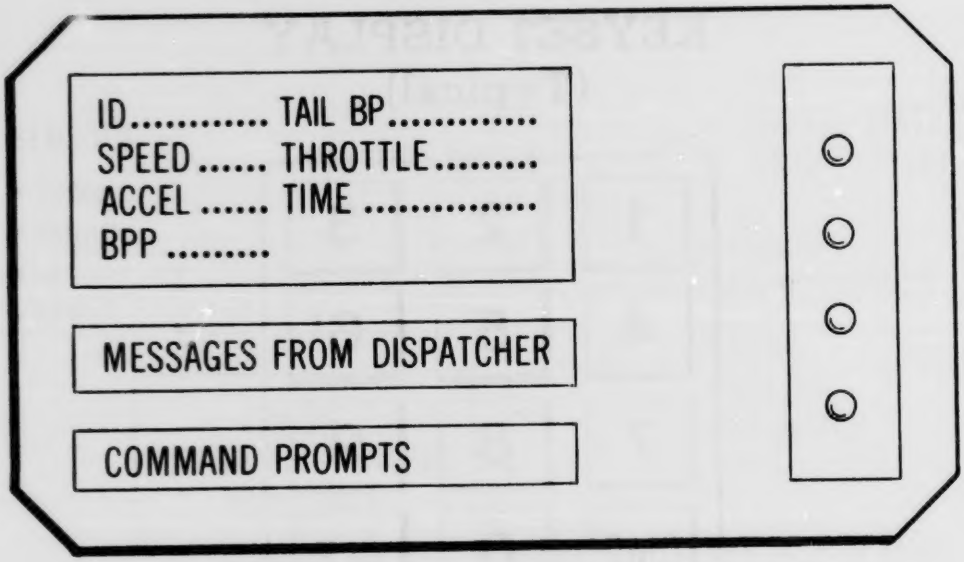
# KEYSET DISPLAY
# (Typical)



In **Signal Verification**, we are talking about the locomotive operator entering signal status on a **key set** as he passes a signal post. This signal status will then be presented to him on a **cab display**, typically shown here on the right-hand side of the CRT unit shown in the colours that he entered. Also the signal status could be transmitted to the train control centre on command.

In **Vigilance Control**, we are talking about the TDRS monitoring various parameters inside the locomotive, typically throttle and brake pipe pressure, for changes. If changes are not detected in a certain time interval, an audible alarm one would be activated. Audible alarms 2, 3 and 4, having increased pitch and volume would be sounded if further activity is not detected. The audible alarm would be reset by changes in throttle or brake pipe or depressing the key set or foot pedal. **Vigilance alarm 4** is transmitted to the dispatch control and finally a **relay control** for stopping the train is enabled.

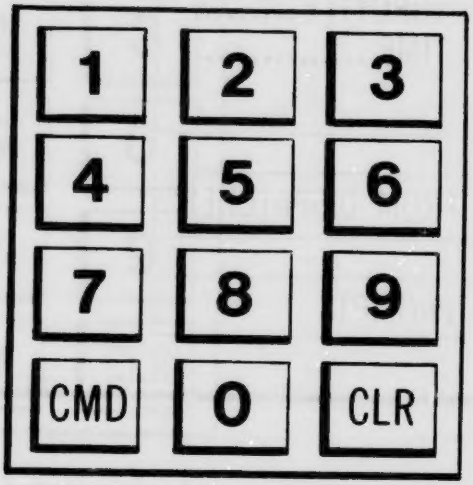
# CAB DISPLAY (Typical)


ID............ TAIL BP.............
SPEED...... THROTTLE.........
ACCEL...... TIME...............
BPP.........
MESSAGES FROM DISPATCHER
COMMAND PROMPTS

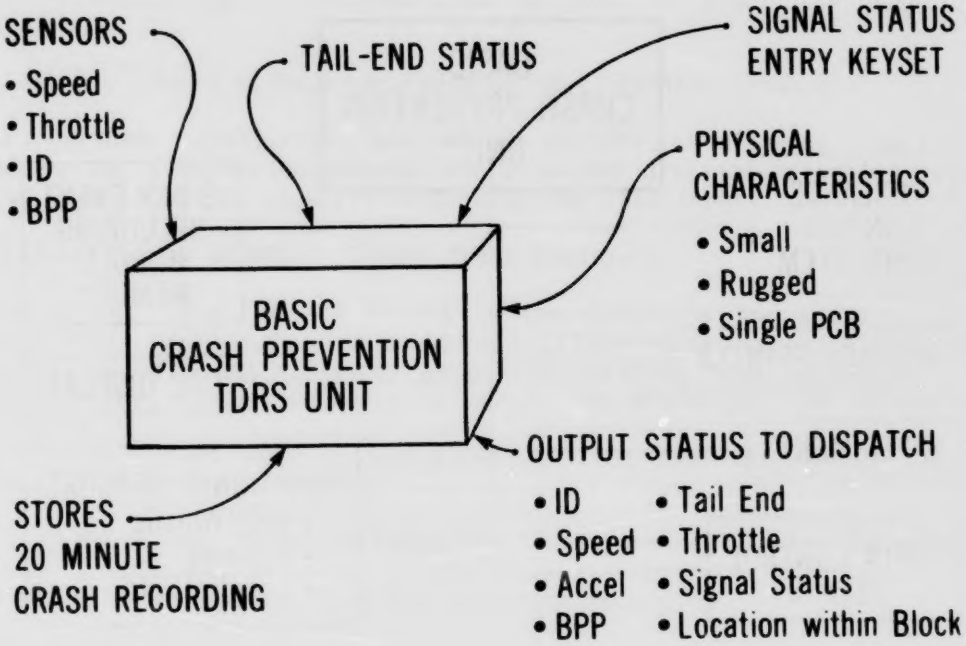
A **Typical Cab Display** would be one having four fields. The top field would provide for the operator a list of critical parameters which are **identification, speed, acceleration, brake pipe pressure, tail-end pressure, throttle position** and **time.** The second field down on the left would be **messages from the dispatcher.** The field at the bottom would be a **command prompt** to the operator. For example, he would have a very simple keyset and the commands would be very short numerical commands and the prompt for those commands could be displayed at the bottom of the screen for making the system more friendly for the operator. And then finally, on the right-hand side, you have the **signal status display** which is for the operator a verification of what he saw on the signal post a couple of minutes ago.

# KEYSET DISPLAY

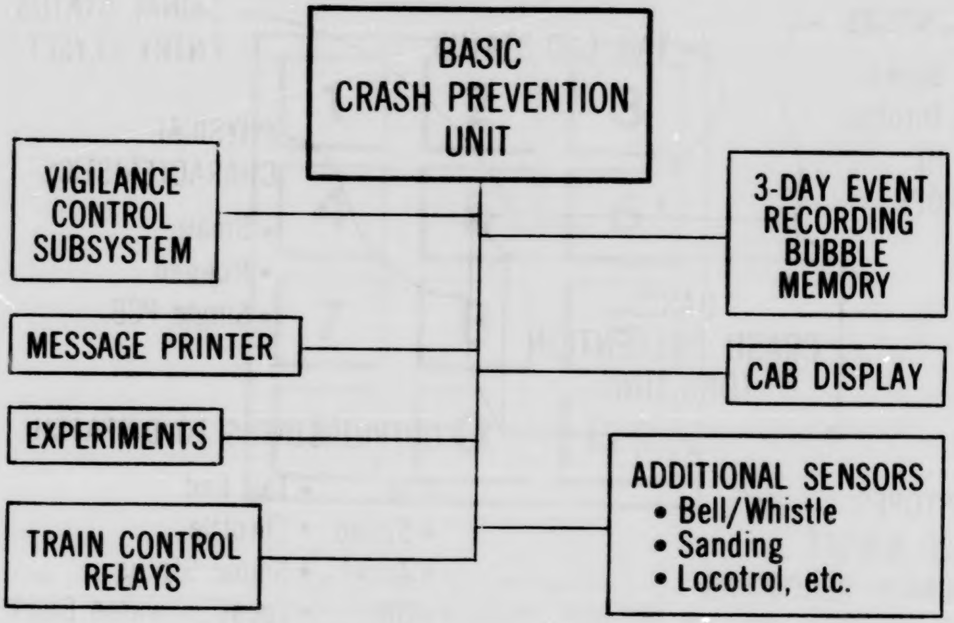
## (Typical)



And finally, the **Keyset** could be something very simple providing a numeric pad, a command key and a clear key, so by just depressing the command button and a series of numerals he could enter a command or, if he wanted to, half-way through the commands, clear it, or cancel it, by just pressing the clear button.


SENSORS
• Speed
• Throttle
• ID
• BPP
TAIL-END STATUS
SIGNAL STATUS ENTRY KEYSET
PHYSICAL CHARACTERISTICS
• Small
• Rugged
• Single PCB
BASIC CRASH PREVENTION TDRS UNIT
OUTPUT STATUS TO DISPATCH
• ID
• Tail End
• Speed
• Throttle
• Accel
• Signal Status
• BPP
• Location within Block
STORES 20 MINUTE CRASH RECORDING

Our concept of a **Basic Crash Prevention Unit** would be physically small and rugged and consist of a single printed circuit board. It would monitor the most critical train operating parameters (speed, throttle, automatic brake pressure, tail-end status and signal status input from operator's keyset) and store approximately twenty minutes of recording in retrievable memory, in case of an accident. Periodically, or upon receipt of an interrogation message from dispatch control centre over a radio data link, the unit would output its identification and current status back to dispatch control over the radio data link.


BASIC CRASH PREVENTION UNIT
VIGILANCE CONTROL SUBSYSTEM
MESSAGE PRINTER
EXPERIMENTS
TRAIN CONTROL RELAYS
3-DAY EVENT RECORDING BUBBLE MEMORY
CAB DISPLAY
ADDITIONAL SENSORS
• Bell/Whistle
• Sanding
• Locotrol, etc.

Add-on accessories for the basic TDRS unit would include:

- 3 day event recording (bubble memory cassette)
- vigilance control sub-system
- cab display
- message printer
- additional sensors
- train control relays

Thank you very much.

## DISCUSSION ON PRESENTATION BY G.F.GUEVARA AND R.J.CLARK

M. KELLEY (DSL): Does your system require the operator or engineer to input an absolute location at the beginning of a run?

R.J. CLARK: Yes. It does require that he enter the starting mile location.

M. KELLEY: Would he have knowledge of that absolute location?

G.F. GUEVARA: Well, right now, we are calculating distance from tachometer and so the distance we provide would be the distance travelled calculated from when an actual subdivision mileage was last input.

M. KELLEY: How do you deal with track equations?

R.J. CLARK: What we are hoping in the future is for a track transducer which would provide us with on-going location messages, which could then be correlated with the distances we are calculating from tachometer. At the present time, all we are doing is calculating distances from tachometer.

M. KELLEY: Does your system allow for the operator during the run to actually change his location?

R.J. CLARK: Yes. With the keyset he can periodically enter location.

M. KELLEY: How does this affect the crash recording?

R.J. CLARK: Not at all.

M. KELLEY: Thank you.

W. SERGEANT (CANAC): I am a bit puzzled at the choice of words or at the choice of the title in one particular item that you talked about - an accident prevention unit. I did not quite see how that prevents accidents.

R.J. CLARK: I guess we are trying to be more positive in the name of this unit. We think that probably when you add vigilance to the system, and you also provide in future a feed-back to the dispatcher, then the unit does provide more crash prevention facilities than what the basic recorder does at the present time. But in order for it to provide real crash prevention, you need these two developments - that is a radio link back to the dispatcher so that the dispatcher can know where the train is at any particular time and also vigilance control to make sure that everything is working properly inside the cab.

P.A. LAROSE (CANAC): One of the operating rules in the railway is that the crews are supposed to call a signal to each other and I was wondering if you looked at the possibility of having two input modules so that the logic would reconcile the end-feed information?

**R.J. CLARK:** Yes, we provide enough interfacing on the basic controller for adding not just one but several other devices. One could be a second keyboard, a second keyset so that both the operator and his assistant could enter signal verification and it could then be checked before before being displayed, or you could provide both displays so they could look at them together. There is no reason why that can't be done, for very little extra cost.

**D.H. WALKINGTON (CP Rail):** Having some responsibilities for signals I was interested in your discussion concerning the entering of what the engineman observes but I am curious as to what would happen if he input the wrong information. What action do you see being taken at that point? What is the purpose of this?

**R.J. CLARK:** Well, we incorporated the signal verification after consultations with personnel from CN and the person who was talking to us thought it would be very nice to have a display of the signals as he saw them first, so that a minute or two later, he does not have to think what it was he really saw.

He would keep a permanent copy locally of what he had first seen, but you are quite right. He could make a wrong entry but if he makes it, if he enters it before the signal is passed, then he can still eyeball the two, both his display and the signal mast, and make a change if he entered it incorrectly, and of course, if you have a second keyset, as the other gentleman suggested, then the chances of an error here are really diminished by quite a lot.

**D.H. WALKINGTON:** Okay, so it is a recording system rather than anything more than that, for short term purposes or perhaps long term purposes.

**R.J. CLARK:** Exactly. But you could extend that, as systems became more sophisticated, to a message from wayside that would provide a signal status.

**D.H. WALKINGTON:** Yes, perhaps, that is right.

**R.J. CLARK:** But, like I say, that is a sophistication that you would not intially need.

**D.H. WALKINGTON:** Okay, and that was not part of your concept?

**R.J. CLARK:** Not initially.

**D.H. WALKINGTON:** Thank you.

# EVALUATION OF EVENT RECORDERS

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## ABSTRACT

This paper describes an evaluation program of two commercially available event recorders, the Pulse Model 48H8-C-10 and the Hasler-Teloc-2000 DR undertaken by the Transportation Development Centre (TDC), at the request of the Railway Transport Committee (RTC). The program was carried out in conjunction with the RTC, Canadian National and CP Rail. The objective of the project was to determine the operational suitability for accident investigation of locomotive event recorders that were potential candidates for installation on Canadian locomotives.

Both recorders that were evaluated recorded at least the following eight required events: time, speed, throttle level, brake pipe pressure, independent brake cylinder pressure, locomotive initiated emergency, whistle and distance.

For the evaluation, 10 Pulse recorders were installed on CN locomotives and 8 Hasler recorders were installed on CP Rail locomotives. During the evaluation period, there were no operational or maintenance problems associated with the recorders. Accident simulation tests were performed that involved recording, in parallel, the identical signals that the event recorders were recording. For each test, the data from the different sources were compared and the event recorder data were generally found to be extremely accurate. The general test results for both recorder models indicated that the recorders could survive under the operating conditions encountered on a diesel locomotive and record and retain reliable data.

# EVALUATION OF EVENT RECORDERS

## 1. INTRODUCTION

### 1.1 Background

Although this evaluation project started in approximately 1983, both Canadian National Railways and CP Rail had demonstrated an interest in event recorders at a much earlier time.

Canadian National involvement started in 1971 with the development of a specification and subsequent manufacture of a recorder by a Canadian organization. A number of recorders were produced and underwent a test and evaluation program. This comprehensive program indicated that the recorders required extensive repair and redesign. Due to the costs associated with correcting the recorders, CN, in 1977, made the decision to discontinue the program.

CP Rail involvement with recorders started in late 1974 when an event recorder was installed on a Locotrol master unit. System improvements were completed in 1978, after which CP purchased and installed a number of units for locotrol operation.

Discussions that took place within the Railway Safety Advisory Committee (RSAC) of the Railway Transport Committee (RTC), based on experience of railways to 1980, indicated that it was apparently the general opinion that none of the recorders available at that time had the desired reliability to justify equipping the entire locomotive fleet for only accident investigations. In light of this opinion and faced with accident inquiry recommendations that event recorders be installed, the Transportation Development Centre (TDC) was approached by RTC, with the approval of the RSAC, to undertake an evaluation program in conjunction with RTC, Canadian National and CP Rail.

It was agreed that TDC would fund the acquisition through Department of Supply and Services contracts with each railway, of commercially available event recorders and the railways would absorb the cost of the installation, testing and reporting. It was requested that both railways select a commercially available recorder for the evaluation program.

### 1.2 Purpose

With the limited experience in Canada with locomotive event recorders, this project was intended to assist in determining the required characteristics of event recorders and to provide an opportunity to all concerned to develop a management strategy to handle data. Also since little operating experience was available, the in-service test provided a certain amount of reliability data which has been evaluated as part of the overall project.

### 1.3 Overall Objectives

To facilitate accident investigations through the use of event recorders and to permit improvements in productivity and efficiency of train operations.

### 1.4 Project Objectives

To determine the operational suitability for accident investigation, through performance tests, and analysis of reliability and maintenance data of locomotive event recorders that are potential candidates for installation on Canadian locomotives.

## 2. EQUIPMENT DESCRIPTIONS

### 2.1 Recorded Events

During a meeting of the RTC - Technical Committee on Rolling Stock and Operations in April 1982, the following eight events were selected as the minimum number required by the RTC that would have to be recorded:

a) Time
b) Speed
c) Throttle Level
d) Brake Pipe Pressure
e) Independent Brake Cylinder Pressure
f) Locomotive Initiated Emergency
g) Whistle (Horn)
h) Distance

Based on these requirements, Canadian National selected and evaluated ten Pulse Model 48H8-C-10 locomotive event recorders and CP Rail selected and evaluated eight Hasler-Teloc-2000 DR locomotive event recorders.

### 2.2 Canadian National Equipment

#### 2.2.1 Event Recorder - Pulse Model 48H8-C-10

The data recorder was mounted on the floor of the radio compartment of the locomotive and records the train operating parameters listed in Item 2.1. It stores the data in a Data Pack (magnetic tape memory cassette), retaining the most recent 48 to 52 hours of information. The information to be recorded is transmitted from the locomotive wiring and a pneumatic manifold through multi-cable connectors to the recorder unit.

#### 2.2.2 Pneumatic Manifold

The purpose of the pneumatic (air) manifold, is to integrate into a single housing the pressure transducers and associated circuitry necessary to convert pneumatic measurements to electrical signals suitable for recorders. The installation of a Pneumatic Manifold was under the cab floor of the locomotive.

### 2.2.3 Data Packs

Data Packs are magnetic tape cartridges used with recorders to store data. This is then transferred to paper charts for evaluation through a playback unit. During operation once the memory (data pack) is full, new data overwrites the oldest data in the memory.

### 2.2.4 Playback Unit

The playback system is used to record on a paper chart the data stored in the data packs. The system used during the test period was a Desk-Top model.

The operating features of the system are listed below:

a) The power source for the unit is a 120 Volt A.C. outlet.

b) The speed of the stripchart and the resolution of the distance and time marks can be controlled as follows:

  - in the NORMAL position, marks corresponding to 1-mile, 10-mile and 100-mile increments are superimposed on the speed trace. Elapsed hour and minute marks are available for display.
  - In the EXPANDED position, the stripchart is expanded to 5 times the normal presentation, and 1/4-mile marks are added.
  - in the COMPRESSED position, the stripchart is compressed to 1/5 the normal presentation. Only 10-mile and 100-mile marks are superimposed on the speed trace. Elapsed hours are available for display.

c) The wheel size switches are used to scale distance and speed information in proportion to the size of the wheel coupled to the axle generator. Wheel size is measured and recorded at removal of data pack from recorder.

d) The Playback unit has the capability to duplicate data pack. There are two main reasons to duplicate the information stored and magnetic tape. First, as a back-up in case the original Data Pack is lost or destroyed. Secondly, to edit (copy segments rather than entire tape) from one or several Data Packs.

### 2.2.5 Recorder Verifier

A test connector is located on the recorder's inside panel. An external recorder verifier can be connected to the test plug to verify operation of the entire system.

## 2.3 CP Rail Equipment

### 2.3.1 Event Recorder - Hasler-Teloc-2000 DR

The recorder is mounted in the short hood of the locomotive. This unit gathers, conditions and stores the data, through the use of semi-conductor memory, in raw form in a removable data cassette which is key locked and housed in the central unit (recorder).

### 2.3.2 Data Evaluation System (Off Board)

a) Data converter and diagnostic interface card.

b) Software package on magnetic tape.

c) Graphic desk computer.

d) Graphic printer.

e) IBM computer program on floppy diskette (developed in early 1985).

### 2.3.3 Recorded Events

a) Speed (Analog) Signal

- The actual locomotive speed is recorded by converting the 60 cycle signal generated by the end of axle pulse generator. This signal is then isolated, filtered, compensated for wheel wear, and stored in the data cassette.

b) Throttle Position (Digital) Signal

- The actual locomotive throttle position is recorded by converting the 4 locomotive governor speed solenoid signals and a signal from the generator field contactor when energized. This in turn is stored in the data cassette.

c) Whistle (Horn) (Digital) Signal

- This signal is obtained when the pressure switch, which is in the whistle air line, closes. This pressure switch closes when the whistle is operated and this signal and its duration in time is stored in the data cassette.

d) Dynamic Brake (Digital) Signal

- This signal is only an "ON" or "OFF" signal and does not indicate the amount of dynamic brake being applied.

e) Brake Pipe Pressure (Analog) Signal

- This signal is obtained from a pressure transducer which is installed in the brake pipe and the actual air pressure is received as an analog signal, converted to a digital signal and stored.

f) Independent Brake Operation (Digital) Signal

- This signal is obtained through an ON/OFF condition of a pressure switch that is activated when the independent locomotive brakes are applied.

g) Locomotive Initiated Emergency (Digital) Signal

- This signal is obtained through an ON/OFF condition of a pressure switch that is activated when an emergency brake application is initiated from the locomotive.

h) Train Initiated Emergency (Digital) Signal

- This condition is determined by the brake pipe pressure and the absence of the locomotive initiated emergency signal.

i) Time

- The time is stored as year, month, day, hour, minute and second. This must be set when installing the recorder on the locomotive.

j) Distance

- This is a calculated value in which the playback software integrates the speed and time values.

### 2.3.4 Installation

The event recorders were installed in the short hood of the locomotives, on the operator side above the existing radio equipment. The pressure transducer and 2 of the 3 pressure switches were installed in the control stand, using pipe tees, the 3rd pressure switch was located below the cab floor between the electrical cabinet and the control stand, again using a pipe tee. The interconnecting wiring, 2 harnesses pre-equipped with connectors that mated with the recorder, were run from the recorder to the locomotive control stand where all the required signals were available.

### 2.3.5 Data Cassette

The data cassette contains 16K Bytes of semi-conductor memory (CMOS). It has its own power supply which when plugged into the central unit (Recorder) is supplied by power from the central unit. It also contains a Lithium battery which is used to preserve the recorded data in its memory.

2.3.5 (cont'd)

The cassette interface contains all the necessary logic and supervisory functions to access, check and store the data which the central unit has collected.

The data cassette is key locked into the recorder. The lock also serves as a switch to activate the system and illuminate light emitting diode (LED) on the recorder to indicate that the system is functional.

The data cassette is not associated to any particular locomotive and can be used in any of the locomotives equipped with this type of recorder.

The data cassette receives its identity (locomotive number) from the central unit. This identification is ensured by the pin configuration of the A1 plug which is hard wired to the locomotive.

### 2.3.6 Playback Operation

The playback operation is accomplished by removing the data cassette from the recorder and inserting it into the data converter which is designed similarly to the recorder. The data converter converts the data that is stored in concentrated form on the cassette into ASCII format and transmits it to the desk top computer (Tektronix Model 4052). The data on the cassette is accessed through the computer program which is stored on magnetic tape. The data which is extracted from the data cassette is stored on a separate magnetic tape. Once the transfer of data from the cassette to magnetic tape is completed, the data cassette is no longer required.

The computer program is then used to display the data on its CRT screen and if desired a hard copy can be produced on the Tektronix Hard Copy Printer Model 4611. The data can be displayed in graphic, expanded graphic or tabular form.

A new computer software program has been developed and tested. This new program allows the data to be extracted and formated using an IBM-PC computer in place of the Tektronix one.

### 2.3.7 Operation of Recorder

The recorder is powered with 74 volts DC obtained from the 6 AMP speedometer circuit breaker. When the system is switched on, the state indicator light, a red light emitting diode starts flashing slowly (once per second) indicating that the system is operating correctly. Upon movement of the locomotive the state indicating light indicates the recording of data by flashing at a higher frequency (5 times per second).

The state indicator light is also used to indicate a recorder malfunction by permanently remaining lit; and, if not lit, this indicates malfunction of its power supply, microprocessor or the 74 volt feed.

2.3.7 (cont'd)

Should a failure be detected, the data converter unit contains a diagnostic interface card which can be plugged into the recorder and the problem detected.

## 3. TEST PLAN

A test program was developed to assess the recorders in basicly two areas, performance and reliability and maintenance. The test program was identical for both recorders.

### 3.1 Performance Tests

The performance tests were divided into two groups, the assessment of certain parameters and an accident simulation/accuracy evaluation test.

### 3.1.1 Parameter Assessment

The parameters that were assessed during the program follow:

a) security of memory module from tampering, both physically and switching with another module;
b) handling of memory module in an accident, personnel authorized to remove memory module from locomotive, etc.;
c) length of time memory will remain intact without power from locomotive;
d) method of identifying memory module with a particular locomotive once the module has been removed and security of this method of identification;
e) ability of event recorder to record the required eight events;
f) adequacy of memory capacity;
g) verify that once memory full, new data overwrites the oldest data in the memory module;
h) determine approximate time and/or distance required to fill memory;
i) verify that once memory full and new data being entered, it is possible to distinguish the newest data entry from the oldest.

### 3.1.2 Accident Simulation/Accuracy Evaluation Test

This test was undertaken to ensure that the data being recorded was done in sufficient detail and accuracy so that it could be used in the accident investigations. The following was performed:

a) perform test runs, with a suitable consist, at various speeds, to simulate crossing collisions;
b) install a calibrated independent recording system, such as a strip chart recorder, for comparison purposes and as a means to assess the performance of the event recorder;

3.1.2 (cont'd)

c) vary the maximum number of recorded events possible, during each run, including, throttle position, speed, brake pressures, number of times whistle is activated, etc.;
d) activate both systems to record the events during each run.
e) analyze and compare the strip chart data with the data from the event recorder.

### 3.2 Reliability and Maintenance Evaluation

Throughout the evaluation period, information on the reliability and maintenance performance of the recorders was collected and then reported at the completion of the project.

## 4. TEST RESULTS

A description of the test results for both recorders follows in separate sections. The description format is identical to that presented in Section 3 - Test Plan.

### 4.1 Canadian National - Pulse

#### 4.1.1 Parameter Assessment

a) The recorder is equipped with a hasp for the application of a seal or padlock to prevent tampering with the Data Pack.

The electric cables that plug into recorder are too accessible and can be removed at anytime, when the plug(s) are removed from recorder, the memory module (Data Pack) will stop recording, and will only be re-activated when plug(s) are reapplied to the recorder. Some form of locking device is required in order to prevent tampering with control cables.
b) The personnel responsible for Data Pack recovery is to be the Transportation Officer at the scene of accident.
c) The life expectancy of the recorded information on Data Pack is indefinite.
d) An information and identification tag is applied to the Data Pack every time it is applied to recorder. The information requested to be written on the label at removal of Data Pack includes locomotive road number, recorder serial number, installation date and location, removal date and location, train number and time, wheel size at removal.
e) The event recorder records the desired eight(8) events. A more complete assessment of this parameter is contained within section 4.1.2 Accident Simulation/Accuracy Evaluation Test.
f) The recording capability of Data Pack is from 48 to 52 hours.
g) Once the memory (Data Pack) is full, new data overwrites the oldest data in the memory (Data Pack).

4.1.1 (cont'd)

h) Time is fill memory (Data Pack) is 48 to 52 hours, with distance being relevant to train operation during Data Pack time cycle.

i) It is possible to distinguish the latest data entry in Data Pack from oldest entry, as the Play Back system writes an end of tape mark on Data Pack when the Reset/Operate switch on the Play Back unit is depressed.

### 4.1.2 Accident Simulation/Accuracy Evaluation Test

The accident simulation test was performed on February 7, 1984, on event recorder equipped locomotive unit 9514 in a consist that included the CN R&D Test Car. The calibrated independent recording system (brush chart recorder) of the CN R&D Test Car was used as the means to assess the performance of the event recorder. The test run was made between Montreal and Rouse Point.

Test runs were performed at various speeds during which the maximum number of recorded events was varied during each run, including speed, throttle position, brake and horn. Both event recording systems were activated to record the events during the test runs.

The strip chart data from both the Pulse recorder on unit 9514 and the R&D Test Car were analyzed and found to compare favourably. The one slight exception involved the recording of each whistle (horn) event. Although the Pulse recorder indicated correctly when the whistle was blown, it did not always indicate the correct number of times the whistle was used. In cases where the whistle was actually blown four or more times, the Pulse chart might have only shown two dashes.

If detailed data comparison between the Pulse and brush chart recorder is desired, the report(1) prepared by CN Rail on the event recorder evaluation provides examples of the recorded events obtained from the test runs.

### 4.1.3 Reliability and Maintenance Evaluation

The ten Pulse event recorders were in service for over one year and were proven to be reliable.

Since the initial installation of the recorders, no maintenance problems were reported.

The general crew reaction seemed to be favourable as no verbal or written objections were received by CN during the evaluation period.

## 4.2 CP Rail - Hasler

### 4.2.1 Parameter Assessment

a) The security of the memory module is provided by a key lock mech-mechanism which not only secures the module in place but also activates the system to indicate proper connection and operation. The memory module receives its identity from the locomotive into which it is inserted and therefore can be interchanged without any problem.

The recorders were installed with a strap located beneath the connection plugs to avoid unauthorized disconnecting.

b) In the event of a mishap the crew would deactivate the system and proceed to a main terminal and have an authorized person remove the module. In the event that the locomotive could not be moved, authorized personnel would be dispatched to remove the module.

c) The memory module contains a Lithium battery which has a life span of 2 years. There is also a "low power battery" warning on the data transfer unit to indicate battery condition.

d) The memory module receives its identification from the locomotive into which it is inserted. It also contains Lithium batteries which preserves this recorded data.

e) The recorder recorded the eight events without any problems or difficulties.

f) The recording of the 8 events which would be analyzed to indicate the chain of events prior to a mishap is more than adequate.

g) The memory module was tested and data removed from numerous locomotives runs and only the final 3 hours of operation prior to removal were present.

h) When the recorders were first installed the data sampling rate was once every second regardless of locomotive status. This condition was changed with no sampling carried out when the locomotive was stopped. With the present sampling rate of once per second the time required to fill the memory is 3 hours of locomotive operation during movement.

i) The memory module contains the last 3 hours of locomotive operation, each entry of data is preceeded with a clock time indication which allows easy and positive identification of newest or last data entries.

### 4.2.2 Accident Simulation/Accuracy Evaluation Test

The accident simulation test involved recording, in parallel, the identical signals that the event recorder recorded. The two recordings were then verified signal by signal to ensure that both were identical in events recorded and, duration in time. This test was performed on March 5, 1985, using CP Rail diesel locomotive road number 5942. Dynamometer test car 62 was instrumented with an eight channel brush chart recorder to record the data. The test was conducted on the M & O Subdivision between Vaudreuil and Rigaud. Present during the test were Messrs. D.W. Dibble, Transportation Development Centre, D.R. Gallacher, Davanac, P.E. O'Brien and A. Clark, CP Rail.

### 4.2.2 (cont'd)

The test was conducted in 2 runs with a different data cassette used on each run. One run was made from Vaudreuil to Rigaud and one from Rigaud to Vaudreuil.

The locomotive was operated in such a fashion as to use or operate frequently each event that the recorders were monitoring.

The data from both recording systems were analyzed, compared and found to be extremely accurate.

If detailed data comparison between the Hasler and brush chart recorders is desired, the report(2) prepared by CP Rail on the event recorder evaluation provides examples of the recorded events obtained from the two test runs.

### 4.2.3 Reliability and Maintenance Evaluation

The reliability of the 8 recorders that were being evaluated was more than acceptable; only 3 components required replacement, 1 pressure transducer and 2 pressure switches. These components are not part of the recorder and these failures could be considered infant mortality. The recorders did not require or receive maintenance. The only work associated with them was the change-out of memory cassettes for extraction of data to ensure proper operation of all events recorded.

## 5. CONCLUSIONS

The results of both evaluation programs indicate that each event recorder can survive under typical locomotive operating conditions and record and retain reliable data.

The current microprocessor based event recorders can be expanded to include such duties as vigilance control, as some do now. This flexibility would permit the event recorder, or actually its microprocessor, to undertake a diversity of roles.

Taking the question of event recorders one step further than this evaluation program addressed, it is becoming more and more apparent that with the advent of microprocessors on-board the new generation locomotives, event recording will become just one of many functions assigned to a particular on-board microprocessor. In addition, the Advanced Train Control System (ATCS) specifications have at least identified the possibility of recording selected events. If these trends continue, it would be surprising if, in the future, new locomotives did not come equipped with on-board micro-processors to serve as event recorders, vigilance controllers, and health monitors, in addition to the host of activities specified in ATCS.

## 5. (cont'd)

It can be concluded that judging from the equipment available now and that which should be developed in the future, reliable recording of locomotive events is possible now and these devices will become increasingly sophisticated and diversified with time.

## 6. RECOMMENDATIONS

The CN report(1)recommends that the following design changes to the Pulse recorder should be undertaken:

a) Installation of the recorder box should be permitted in more than just the horizontal position.

b) A self-test button should be added.

c) Pressure switches and transducers should be separate units to eliminate the extensive underfloor piping currently required.

d) A much more expanded scale on the recorded data strip chart would be useful.

One aspect not evaluated in the program was the mounting location for the recorder. It is recommended that if event recorders are to be used for accident investigation purposes then as secure a location as possible should be chosen in order to protect them from, for example, collision damage. However, in order to access the memory, certain trade-offs may have to be made as far as location is concerned. On recorder models requiring the physical removal of the memory, the mounting location would have to be fairly easily accessible. On other recorders, including a new Hasler design, the recorder memory can be accessed from a remote location. General access then to the actual recorder, under this circumstance, would only be required for periodic maintenance and would theoretically permit the recorder to be mounted in a fairly secure location even if this meant that it was somewhat difficult physically to access.

Memory capacity or in general terms, operating time needed to fill the memory requires careful study. It is recommended that accident statistics be studied in order to determine how much time before an accident occurred would be critical for an investigation. This information would provide the minimum acceptable recorder memory capacity. At this point, it is difficult to state whether the last 10, 20, 30 minutes, etc., would be needed for a particular accident investigation. This question is not relevant for recorders having memory capacity measured in hours, but in cases where the capacity is quite limited, it becomes a critical consideration.

6. (cont'd)

The question of which event data should be used to initiate recording is quite important. It is quite feasible, if, after an accident, the locomotive remains powered, that data, perhaps only zeros but nevertheless data to the recorder, will keep being recorded and possibly wipe-out the accident data. It is suggested that the existance of a speed signal be used to determine that data should be recorded. In the case of an accident, a powered locomotive could sit for days, ie; no speed signal, and therefore no data would be recorded and there would be no chance that the accident data might be over-written.

## REFERENCES

(1) Lusk, R.J., and Lauzon, R.: **Locomotive Event Recorders - Field Evaluation: Pulse Model 48H8-C-10,** CN Rail, Montreal, December 1984, **TP 6219E.**

(2) Clark, A.K.: **CP Locomotive Event Recorder Evaluation,** CP Rail, Montreal, August 1985, **TP 7240E.**

## DISCUSSION ON PRESENTATION BY D.W. DIBBLE

C. GANNETT (U.S. DOT): Is the Transport Commission considering making if a requirement that locomotives be equipped with the recorders?

D.W. DIBBLE: I believe they have been considering that. It would be more appropriate if the RTC would answer any further questions on that.

P.A. LAROSE (CANAC): Could you comment on the crash survivability of these devices?

D.W. DIBBLE: That is a very good question and I go into that in more detail in the actual paper. The mounting location of the recorder has to be selected very carefully. You want to pick the safest location in the locomotive, considering a head-on collision or an accident involving fire. We looked at some recorders that might not survive in a fire. There are recorders on the market now that I think would survivie most accidents. There is a question of a price trade-off, but there are some available that I think would survive most accidents.

P.A. LAROSE: Is it a general rule to locate the recorder in a head-end unit and in the cab?

D.W. DIBBLE: For this evaluation, it was done as an experiment primarily because that was a very accessible locaiton. A better location would have to be picked for actual accident investigation purposes and you would have to trade off the requirement of accessing the memory. Some of these recorders now have remote access so that you can bury the recorder into the frame of the unit and access it via an electrical connection. Then you only have to go to the recorder if maintenance is required, which would be very infrequent.

P.A. LAROSE: Could the recording device be located in a trailing unit, the last of the head-end units, to reduce the possibility of destruction to a certain extent?

D.W. DIBBLE: It does take a little time to install these things. If the recorder was on a trailing unit, it could be activated and record everything except the whistle, which is the only thing that is not trainlined. The whistle could be made available to a trailing unit; it is quite feasible.

P.A. LAROSE: I suppose you could review the possibility of locating it at the rear of the train with the head-end monitoring devices, to emulate the airliners which locate their flight recorders in the tail portion of the plane.

D.W. DIBBLE: Yes, but this does not protect against a train running into the back of another train. Where is the safe location?

**R.W. RADFORD (CN RAIL):** That is a very important point. This recorder, as inititially installed, just recorded continuously. It did not matter what the locomotive was doing. Therefore if you had an accident, and power remained on the locomotive, three hours later you would have sitting data. You would have no information about the accident. This was changed so that recording was based on speed. If the locomotive was not moving, nothing was recorded. It is very important in short term memory that you don't lose it because of improper selection of the recording criteria.

**W. MOORE EDE (CN RAIL):** I found your presentation very interesting. I have a couple of comments. First, the data that is being recorded is the same that is going to be needed in other places for various other developments. It is therefore important to ensure that the data recorder is not a stand-alone device, so that you can get access to that data for whatever reason, rather than having to store it in a multitude of different places. The second comment is that I would think the industry would want to concentrate on preventing the accident rather than recording what has happened after the fact. I think the ATCS project is attempting to address this point.

**D.W. DIBBLE:** I think you are right in both your comments. New locomotives coming out now have microprocessors on them and it probably would not be difficult to use them as an event recorder. We were looking at early 80's equipment and they did not have this capability.

**W. SERGEANT (CANAC):** This subject is pretty well oriented towards accident recorders and accidents and what happened at the moment of an accident. Has any thought been given to using this information for other purposes, and whether you can derive beneficial knowledge from it to enhance regular train operation? Could it also have some benefit in the manner in which a train affects tracks or anything like that?

**D.W. DIBBLE:** The ultimate system should be used for more than just an accident recorder. For the amount of money you have to spend on this equipment, you would like it to do more than just tell you about an accident. I think a sophisticated piece of equipment is needed that can be used for train handling and for training as well as an accident recorder.

It is going to be up to the railways to decide how much money they want to spend on a piece of equipment. You just get a basic accident recorder if you don't want to spend much. For other uses, the railways are going to have to spend a bit more money to get a more sophisticated piece of equipment. The Hasler system has been upgraded substantially to include vigilance control and monitoring of other information. It is being purchased by CP Rail to get more use out of it than just accident recording, so these developments are ongoing.

**B. LONGSON (CONSULTANT):** I am presently involved in the inquiry into the Hinton train collision. Are the railways in agreement with your evaluation of these devices? Were they involved in the testing?

**D.W. DIBBLE:** My conclusions are taken almost verbatim out of their report.

## 2.5 Technical Session #2 - Track and Infrastructure

### Session Chairman

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# RAIL WEAR AND CONTACT FATIGUE MODEL UTILIZING LUBRICATION AND GRINDING TO EXTEND RAIL LIFE

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## ABSTRACT

Rail located in curves of heavy haul railway lines may experience four different modes of wear: gouging wear at the gauge face and oxidative wear on the rail's top surfaces in the case of unlubricated rail, and delamination and mild abrasive wear if the rail is lubricated. Lubrication, whilst effectively controlling the gouging wear, leads to the development of contact fatigue corrugations. Based on the analysis of contact fatigue crack initiation and propagation, a new method of grinding is proposed. It is shown that this method can prevent the development of contact fatigue corrugations and substantially increase rail life.

## 1. INTRODUCTION

Hundreds of millions of dollars are spent annually to replace rails in curves and tangent track on heavy haul railway lines worldwide. In the broadest sense, rail life is affected by one or a combination of the following mechanisms: wear, contact fatigue and fatigue failures. Wear and contact fatigue compete to limit the rail life by damaging the surface or subsurface layers of rail material whilst the fatigue failures, including deep shells, transverse and detail fractures, affect deeper sections of the rail head or the entire cross-section of the rail. The analysis of fatigue failures is beyond the scope of this paper.

Two forms of adhesive wear may occur on the rail surface. A mild form prevails on the rail's top surface whilst a severe form, referred to as gouging or sidecutting, prevails at the gauge face surface in curves. Although the gauge face wear can be controlled to a certain degree by the hardness and cleanliness of the steel or by the usage of self-steering trucks, field experience and laboratory tests have shown that wear is most effectively controlled by lubrication.

Lubricant applied to the gauge face/wheel flange interface always contaminates rail top surfaces and reduces wear. When the wear rate recedes beyond a certain value, the fatigue limit of the surface layer is reached before it can be worn away. Numerous surface cracks appear, some of which propagate to a depth of several millimeters. Unlike most fatigue failures caused by cracks propagated by tensile stress field at their tip (Mode I), the near surface cracks in rail are propagated by shear stress (Mode II), and the resulting fatigue failure is termed contact fatigue. At its final stage the contact fatigue is manifested by head checks, shelly spots, flaking and associated corrugations. Providing the corrugations are removed periodically by grinding, a longer rail life can be achieved with gauge face lubrication than without it.

This paper describes a new method of rail grinding which is termed "preventive grinding", and the underlying theoretical considerations on which this method is based. Provided the rails in curves remain lubricated all the time without lubrication breakdowns or interruptions of any kind, preventive grinding should bring about a further substantial increase in rail life and maintain the rail surfaces free from contact fatigue corrugations.

## 2. WEAR

Using the 1/10th scale rail/wheel wear apparatus, the wear rates of several commercial rail steels were established for dry, grease-sand and grease only lubrication regimes. The wear apparatus and test procedures used are described in references 1,2. In these experiments rail specimens machined from the heads of commercial rails were subjected to an equivalent of 51 million gross tonnes (60 MGT in U.S. customary units) of traffic experienced by rails laid in a 235 m radius (8°) curve located in a single main line track and experiencing heavy axle loads in both directions. Wear rates were obtained by weighing the disc specimens and are shown diagramatically in Figure 1.

## 2.1 Dry Wear

### 2.1.1 Mild Adhesive (Oxidative) Wear

The examination of wear particles, when compared with findings of other researchers [3,4] has shown that the rail disc or rail top surfaces (Figure 2 locations A-D) experienced mild adhesive wear. The wear rates may change, however, with location A, B, C or D depending on the Hertz pressure and amount of slip. The wear debris varies accordingly in size, about 3 μm to 30 μm in thickness and 10 μm to 200 μm in length. The particles consist of a heavily deformed, cracked and oxidized mixture of rail and wheel material, implying that the particles sequentially adhered to the wheel and rail surfaces several times before they were released from the rail wheel interface. Because of triboxidation of the particles [5] this wear is referred to by many as oxidative wear.

### 2.1.2 Severe Adhesive (Gouging) Wear

The wheel flange/gauge side of rail generates much larger wear particles which are highly visible. The appearance of such particles on the railway tracks inspired a multitude of nicknames such as gouging, snowflaking, moonshine or dandruff being given to this form of adhesive wear. The particles are up to 0.5 mm thick and 3 mm across. They are generated by localized welding of wheel/rail asperities. Subsequent breakage of such welds produces rough gauge side and flange surfaces and very high wear rates.

Wear rates of outer (high) rail discs shown in Figure 1a were generated by both adhesive (gauge face) and oxidative (top surface) wear mechanisms. Assuming that the wear on the top surfaces of inner and outer rail discs was the same, the differential in wear rates between the right and left columns in Figure 1a could be attributed to gauge face wear. The adhesive gauge face wear rates correlate rather closely with the rates observed in the field [6]. These rates are responsible for a short wear life of high rails in unlubricated curves of heavy haul railway lines.

## 2.2 Lubricated Wear

### 2.2.1 Surface Fatigue Wear (Delamination)

This form of wear occurs in lubricated or lubricant contaminated contacts (Figure 2 locations A-E). The surface fatigue wear must not be confused with contact fatigue although both processes involve fatigue mechanisms. The surface fatigue wear occurs at a very shallow depth, not exceeding 0.05 mm (0.002"). Contact fatigue cracks, on the other hand, can reach a depth of about 5 mm (0.2"). During the surface fatigue wear process, the asperity-asperity contacts are always separated by a film of lubricant. As a consequence, no material is removed from the tips of asperities. With the increasing number of contact events, microcracks form parallel to the surface due to the presence of manganese sulphide inclusions or to plastic instability of the material (to be discussed in the next section). Thousands of asperity to asperity contacts may take place to form such cracks, and the particle thus formed does not delaminate immediately. It is removed after an appreciable but undetermined number of loading cycles. For this reason, the delamination wear rates are very low.

### 2.2.2 Abrasive Wear

This wear mechanism occurs with the lubricated track when sand is discharged by locomotives to improve adhesion. The sand's quartz grains are crushed by the wheels into microscopic particles (typically <5 μm) which imbed into the rail or wheel surface and abrade the other. Or the sand particles mix with the lubricant or its residues and abrade both the rail and the wheel. The latter mechanism is identical to polishing using a polishing paste. Whether the above abrasive wear mechanisms act separately or simultaneously, the wear rates are very low permitting the development of surface fatigue wear. Thus, in the lubricated and sanded environment, the surface fatigue and abrasive wear mechanisms occur simultaneously.

## 2.3 Wear Rates

Examination of Figure 1 shows that lubrication very strongly affects the wear rates. In particular:

a) The gauge face, where the fresh supply of grease dilutes if not eliminates the presence of sand, experiences delamination wear, the rates of which are reduced with respect to that of dry, gouging type of wear by a factor of 1:100 to 1:200,

b) The top surface, which is sanded to alleviate the effect of lubricant contamination, the dry, mild adhesive type of wear is replaced by a combination of delamination and mild abrasive wear resulting in the reduction of wear rates by a factor, on average, of 1:20.

Furthermore, Figure 1 shows that the rail type, namely its hardness and sulphur content [7], has a strong effect on the gouging gauge face wear, but a weak one on the top surface oxidative wear rates (Figure 1a). In the lubricated environment, however, the rail type has no effect on the delamination or abrasive wear mechanisms. The above observation suggests that, as long as the rail is sufficiently hard to avoid an excessive plastic flow of railhead material (mushrooming), the lubrication alone can be used to control the gauge face wear.

Unfortunately, the lubricant always contaminates the rail's top surfaces. It reduces the wear to a point at which contact fatigue cracks initiate and grow. These cracks damage and weaken the subsurface layers of railhead material rendering the rail unserviceable well before it has reached its wear limit.

## 3. CONTACT FATIGUE

Like any other form of metal fatigue, contact fatigue failure occurs in two stages - crack initiation and crack propagation. The time till failure is customarily given by a contact stress and number of cycles relationship (S-N curve). To study contact fatigue in a meaningful manner it is necessary to know both of these quantities at each location of rail surface.

The running band on the top of the rail is typically 63 mm (2½") wide but the contact circle or ellipse between the rail and the wheel of a loaded 100t capacity car does not exceed the diameter of a dime at 17.5 mm (0.7"). The rail's running band is wider than the contact area, because individual wheelsets in a train are displaced to either side of the centre of the track and have different angles of attack and thus contact the rails at different locations. In particular, the area of contact intermittently moves from the gauge corner to the centre or field side of high rail and, similarly, from the field side to the centre or gauge side of low rail as the curve is negotiated by the leading and trailing wheelsets of passing trucks - a phenomena referred to as pummelling.

Once the position of the contact and the geometry of the rail and wheel profiles are known, it is easy to calculate the value of the maximum pressure at the centre of contact (Hertz stress, $p_0$) or, if necessary, the distribution of Hertzian stress within the material itself [8]. An examination of contact stress formulas indicates that the Hertz stress is more sensitive to variations in rail/wheel geometry than to those in wheel load. Thus the contact between the flange root and gauge corner of the high rail or between the false flange and field side of low rail will yield, for the same load, much higher contact stress values than at the centre of the rail. Using new and worn wheel profiles matched to the worn rail profiles in 8° curve and experiencing heavy haul axle loads we estimated the average Hertz stress at location B & C, D and A (Figure 2) to be 1,150MPa(167ksi), 1,800MPa(261ksi) and 2,500MPa(363ksi) respectively.

Estimating the average frequency of contact at locations A to D is more difficult because neither direct measurement nor theoretical study of this problem have been made. However, guided by measurements of angle-of-attack and L/V forces in an 8° curve, it is felt that the probable frequencies of contact at the designated locations on worn unground rails are given in Figure 2.

## 3.1 Crack Propagation

Owing to the presence of large compression stresses, the contact fatigue cracks are propagated by the shear stress i.e., Mode II. It was suggested by McClintock [9] and shown by Hearle and Johnson [10] and Regan et al. [11] that the stress intensity factor $K_{II}$ at the crack tip and, consequently, the rate of crack propagation is greatly influenced by friction at the rail wheel interface as well as friction between the walls of the crack $\mu_c$. In particular, the cracks with $\mu_c$ at near zero levels, i.e., when contaminated by lubricant, will propagate faster than the dry cracks with $\mu_c \approx 0.4$ to 0.6. The analysis carried out by Nishida et al. [12] suggest that the crack stops to propagate when $K_{II}$ reaches a threshold value. They experimentally confirmed that a specific type of crack propagated at $\mu_c \approx 0.2$ but did not propagate at $\mu_c \approx 0.5$. Although all of the above mentioned studies investigated the cracks propagating in or opposite to the direction of travel, we assume that the "flaking" and "shelly spot" cracks which propagate in the direction perpendicular to that of travel, behave in the similar manner. That is, those cracks which either reach or initiate at the surface and become contaminated by the lubricant will propagate at an accelerated rate due to low $\mu_c$ and high $K_{II}$, whilst the cracks which do not become contaminated by lubricant, i.e., subsurface cracks or when lubrication is not used will propagate at much lower rates, if at all. Needless to say, the problem of laterally propagating contact fatigue cracks deserves and requires further study.

## 3.2 Crack Initiation

Some mechanisms of crack initiation have been proposed. Some of these suggest that the initiation proceeds at the near surface inclusions and voids, probably by a Stage I fatigue process [13]. Although the role of inclusions in the crack initiation cannot be denied Ghonem and Kalousek [14] have shown that surface cracks can initiate by the plastic instability of the surface layer of material. The surface cracks are those located within the depth of <50 µm and connected at some point to the surface. Most surface cracks are parallel to the surface, but not necessarily as indicated by an optical micrograph in Figure 3a.

Most surface cracks lead to the formation of wear particles. However, when such particles remain in place, due to good lubrication, for sufficient time the surface cracks will branch into deeper layers of rail steel and will continue their growth as contact fatigue cracks.

Surface crack initiation by plastic instability has been investigated using a specially designed test specimen subject to cyclical biaxial loading in a hydraulically actuated fatigue tester. All test specimens were machined from the head of chromium alloyed rail (steel B in Figure 1). The biaxial loading of the specimen followed the cycle of hertzian compressive and shear stresses acting at the rail surface as closely as the controls of the fatigue tester permitted. Because the ratio between shear and compressive stress at the rail wheel interface is given at saturated creepage by the coefficient of friction μ, the biaxial fatigue tester simulated the effect of lubrication at the rail/wheel interface by simply varying the shear/compressive stress ratio. For further details see reference 14.

The effect of lubrication on surface crack initiation is shown in Figure 4. Three curves with shear to compressive ratio of 0.10, 0.18 and 0.30 are shown. The selected ratios are typical of:

(a) $\mu \simeq 0.1$ - delamination wear taking place at gauge face under fully lubricated conditions

(b) $\mu \simeq 0.18$ - delamination and mild abrasive wear on top surface contaminated by grease and sand

(c) $\mu \simeq 0.3$ - mild adhesive (oxidative) wear on dry rail's top surface

The relationship between the wear rates and surface and contact fatigue crack initiation is shown on Figure 5. The wear rates of chromium alloyed steel, taken from Figure 1a,b, were converted into the average "surface recess" rates. Although the delaminated particles could be of any thickness ranging from 5 μm to 50 μm, the line TL indicates that for a rail head contaminated with grease and sand the average rate of recess is only 2.4μm/MGT. Therefore, it takes, for example, 12.5 MGT before a 30 μm thick wear particle is removed from the surface. Next, the surface crack initiation points were related to the MGT's using the pummelling diagram (Figure 2) and contact theory of rough surfaces. At $\mu \simeq .18$ the average rate of surface recess-line TL is less than the time it takes to generate the surface cracks - point K. Therefore, enough time between the crack generation and particle removal, is available for some surface cracks to branch into the subsurface layer and become contact fatigue cracks. At the wear rate represented by line TD ($\mu \simeq .3$) the material is removed from the surface faster than the time needed to generate surface crack - shown by point J. Therefore, in dry wear, the forming surface cracks are removed early and cannot branch into contact fatigue crack.

In general, the number of cycles to initiate surface cracks by plastic instability decreases with increasing contact stress and increasing coefficient of friction at the rail/wheel interface. Thus the effect of lubrication on the initiation of surface cracks is opposite to its effect on crack propagation. While the contamination of crack cavities by the lubricant speeds up contact fatigue crack propagation, the contamination of the rail/wheel interface by the lubricant delays the initiation of both surface and contact fatigue cracks. Preventive grinding, which is to be discussed in the next section, takes advantage of these seemingly opposite effects of rail lubrication.

## 4. RAIL GRINDING

### 4.1 Corrective Grinding

Any rail grinding program which is carried out after corrugations have developed constitutes a corrective method of grinding. The typical corrective grinding criteria require that rail is ground when corrugations are > 0.5 mm(0.020") deep. As a rule, the corrugations grow beyond the specified depth due to non-availability of a grinding train, fire marshall restrictions or other reasons. More importantly, any corrugations which are 0.5 mm(0.020") deep or deeper contain clusters of fully developed contact fatigue cracks which, in lubricated territories, propagate through the surface layer of the rail steel to a depth of several millimeters at a high rate.

Figure 6a shows an example of a normal corrective grind in a curve with average corrugations .625 mm to .750 mm(0.025" to 0.030") deep and with some 1.55 mm(0.060") deep. To make the rail surface longitudinally flat, several passes with a large grinding train are made and the rail is ground (with respect to corrugation peaks), to a depth of 2 mm(0.080"). Although the grinding removes all the corrugations, many cracks are left behind, especially below the deeper valleys of the original rail corrugations. All these cracks are connected to the surface and contain lubricant residues in their cavities. Therefore, these cracks will continue their growth with the passage of the next train, ensuring the early reappearance of shelly spots, flakes and contact fatigue corrugations.

### 4.2 Preventive Grinding

The aim of preventive grinding is to keep the rail free of surface corrugations for its entire life and by so doing to extend that life. Providing the gauge face wear is effectively controlled by thorough lubrication, the preventive rail grinding criteria are as follows:

a) to remove the surface layer of material before it becomes plastically unstable, i.e. before the surface cracks appear

b) to minimize the frequency of contact for each element of material at rail surface

c) to minimize contact stresses

The first criterion dictates the depth and period of grinding whilst the other two affect the grinding profile.

### 4.2.1 Grinding Depth

The depth of cut is given by the depth at which the surface cracks are generated. As discussed in the previous section, this depth is on average 25 µm(0.001") with some cracks generated at 50 µm(0.002"). Therefore, the grinding need not be any deeper, with the exception of location A, Figure 2, than 50 µm(0.002"). At location A we estimated, using Figures 2 and 4, that surface cracks will generate early, at ≈0.5MGT. This gives an unrealistically short grinding period and we suggest that enough material is removed from gauge corner of high and field side of low rails to avoid rail/wheel contact at these locations altogether.

### 4.2.2 Grinding Period

Preventing the occurrence of rail/wheel contact at location A alters the frequency histogram. A new pummelling diagram typical of a preventive grinding profile is shown in Figure 7. Using Figures 4 and 7 we estimate that the surface cracks in the sharp curves (>2.5°) will not appear before 10MGT and 6MGT at locations B & C and location D, respectively. New rail may initiate surface cracks very early, say at <5MGT, due to the presence of mill scale, a decarburized layer and other surface imperfections and irregularities.

Based on the above arguments, it is proposed that new rail, whether located in curves or tangent track, is preventively ground immediately or as soon as practical after laying. Thereafter, the preventive grinding period for a sharp curve should be 5MGT. The total amount of material removed due to wear and grinding from the top surface of lubricated and preventively ground rail located in sharp curves, is approximately equal, as shown in Figure 8, to the amount of material removed by oxidative wear in an unlubricated curve.

Since in shallow curves (<2.5°) the number of wheelsets which negotiate the curve at a saturated lateral creepage is reduced, say by 50%, we propose that the preventive grinding period is doubled on these curves to 10MGT. Taking into account the creepage considerations only, we find that, in tangent track, surface cracks initiate ≈30 to 50MGT. At the welds, however, they will initiate much earlier.

To summarize, preventive grinding requires that a single pass of the grinding train removes no more than 0.050 µm(0.002") of material each 5, 10 and 15MGT in sharp (>2.5°), mild (<2.5°) curves and tangent track, respectively. This can easily be achieved by dividing each siding-to-siding section of a single line track, typically 18 km (10 miles) long, into several sections: a section of sharp curves, two sections of mild curves and three sections of tangent track. The grinding train passes over the territory each 5MGT and grinds all the sharp curves, half of the mild curves and a third of tangent track sections, so that all the mild curves and tangent track are ground once each 10 and 15MGT, respectively. Even with an appreciable number of curves, the grinding train could cover a siding-to-siding length of track in 1 to 1½ hour and 800 km (500 miles) of main line track in 8 to 10 working days.

### 4.2.3 Grinding Profile

To grind a complete preventive rail profile in a single pass requires a minimum number of 30 stones (15 stones/rail). To satisfy the preventive grinding criterion b) the stones are set "flat"(meaning the stones are tilted <4°) at locations D (Figure 7), to widen the rail's top surface and thus reduce the frequency of contact at locations B and C. To minimize the contact stresses the stones are set to grind the rail's top surface to a radius of ≈35 cm(14") inclined in a ratio of 1:40 towards the gauge on both rails. As shown in Figure 9, nine stones/rail are used to grind rail crown in curves and tangent track alike. The six remaining stones/rail are profiling stones which should remove enough material to prevent wheel contact at location A. However, only three stones/rail are used in any one curve. In right hand curves the right hand group of profiling stones (three at gauge corner of high and three at field side of low rail) grind, while the left hand group of profiling stones are out of engagement. In left hand curves the situation reverses. In tangent track both right and left profiling stones are out of engagement. A grinding pattern similar to the above can be designed if more stones are available. To achieve the desired depth of cut of ≈0.050 mm(0.002") the setting of power consumption at grinding motors, type of stone and the speed of the grinding train have to be determined by field tests.

## 5. RAIL LIFE AND CONCLUDING REMARKS

Rail life in curves, namely that of the outer (high) rail in curves is most severely limited by dry wear. As shown in Figure 5, line GD, gouging wear removes the rail material from the gauge face of the rail at a high rate requiring rail in an 8° curve to be replaced every 40 to 100 MGT (depending on rail type).

As shown in Figure 1, lubrication can effectively arrest gauge face wear but it contaminates the rail's top surface and brings about the initiation and growth of contact fatigue cracks which develop into head checks, shelly spots and flakes, and cause the rail to corrugate. Whether the rail is lubricated and correctively ground or lubricated and preventively ground, the rail becomes condemnable if more than 19 mm(0.75") (measured vertically) is removed from the rail head surface. If we use the previously mentioned example of corrective grinding (Figure 6a) which removes 2 mm(0.080") of material from the rail head surface each 25MGT then the rail becomes thin at 235MGT. Although this represents a substantial increase in rail life with respect to dry wear, a further increase can be achieved if the rail is ground preventatively.

Figure 8 predicts that the combined material removal from the top of chromium alloyed rail due to wear and preventive grinding is 16 μm/MGT. In fact, a somewhat increased wear rate will occur due to the roughening of the rail surface by the grinding stones and we feel that the combined wear-grinding rate of 25 μm/MGT (0.001"/MGT) is more realistic. At this rate the high and low rails in sharp curves become thin at 750MGT and at about twice and three times this period in mild curve and tangent track respectively. This, compared to corrective grinding, represents a threefold increase in rail life.

The thorough lubrication and preventive grinding policy provides the railway industry with a tool to substantially increase rail life in curves and tangent track alike. It also should enable the railways, for the first time, to be in full control over the rail corrugation problem and a rail grinding program. Finally, the cost of preventive grinding is estimated to be lower than the cost of corrective grinding [15].

## ACKNOWLEDGEMENT

The National Research Council and the author would like to thank the Transportation Development Center for their continued financial support and encouragement.

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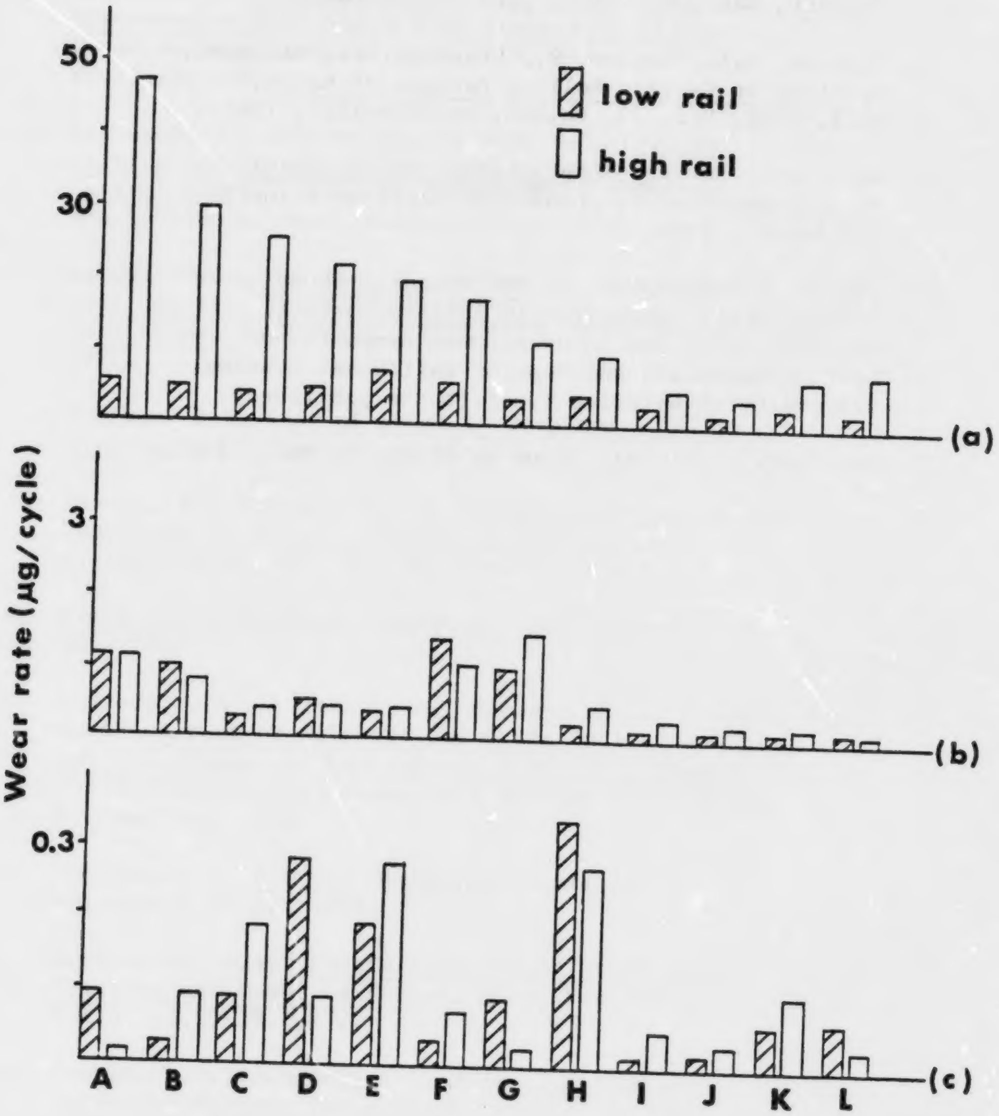


FIG. 1: Wear rates observed on commercial rail steels with (a) no lubrication (b) lubricated by grease-20% sand mixture (c) lubricated by grease. Note the scale changes in (a), (b) and (c). Steels: A--Standard carbon; B Alloyed--1% Cr; C--Heat Cr-Mo I; D--Russian FHT; E--Alloyed-Cr-Cb; F--Fully heat treated; G--New head hardened; H--Australian head hardened; I--Chromium enhanced; J--Head hardened and chromium alloyed; K--AWC300; L--AWC340.

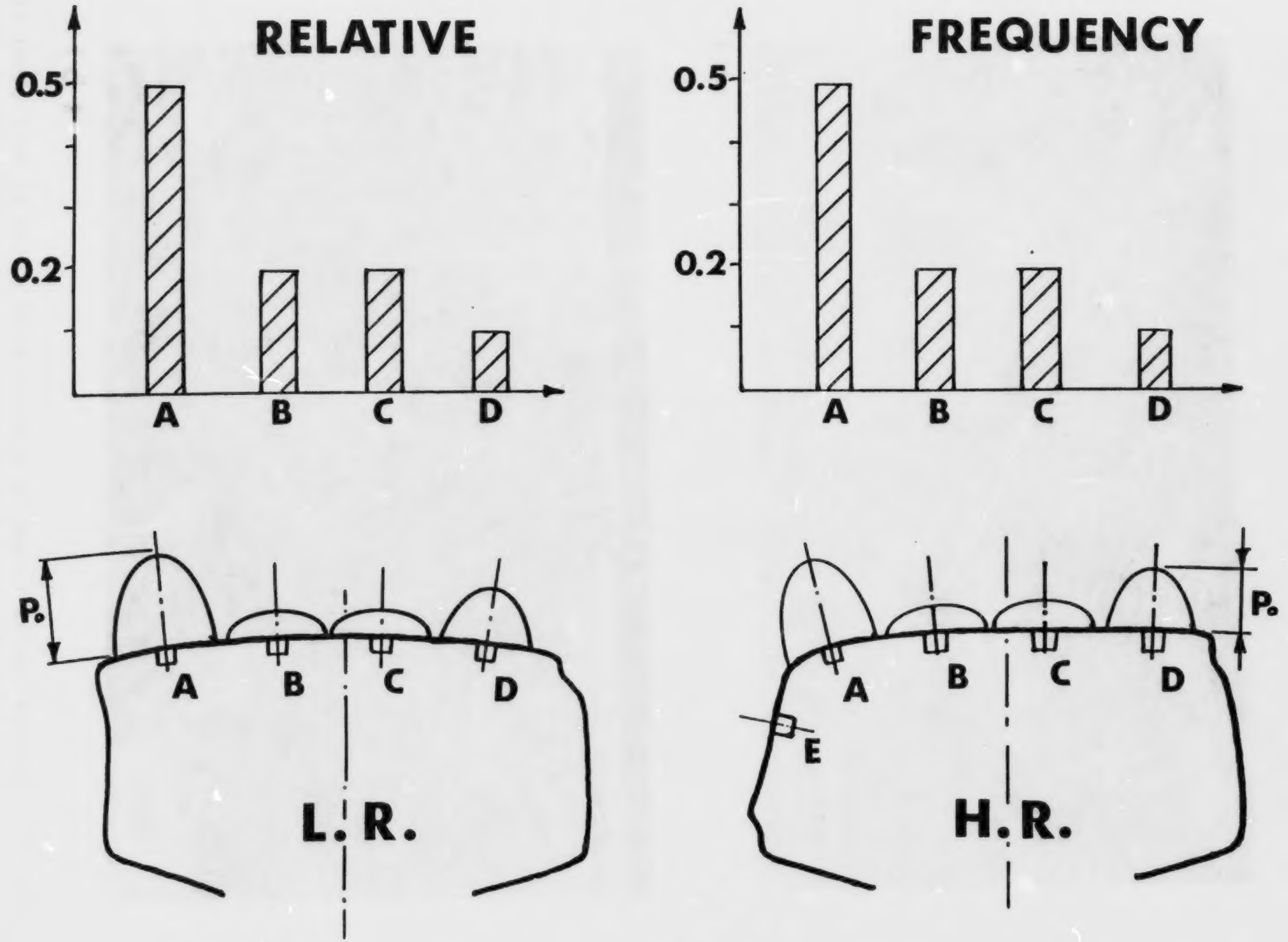


FIG. 2: Frequency histogram (pummelling diagram) of rail-wheel contact for naturally worn rail in 8° curve. HR--outer (high) rail, LR--inner (low) rail.

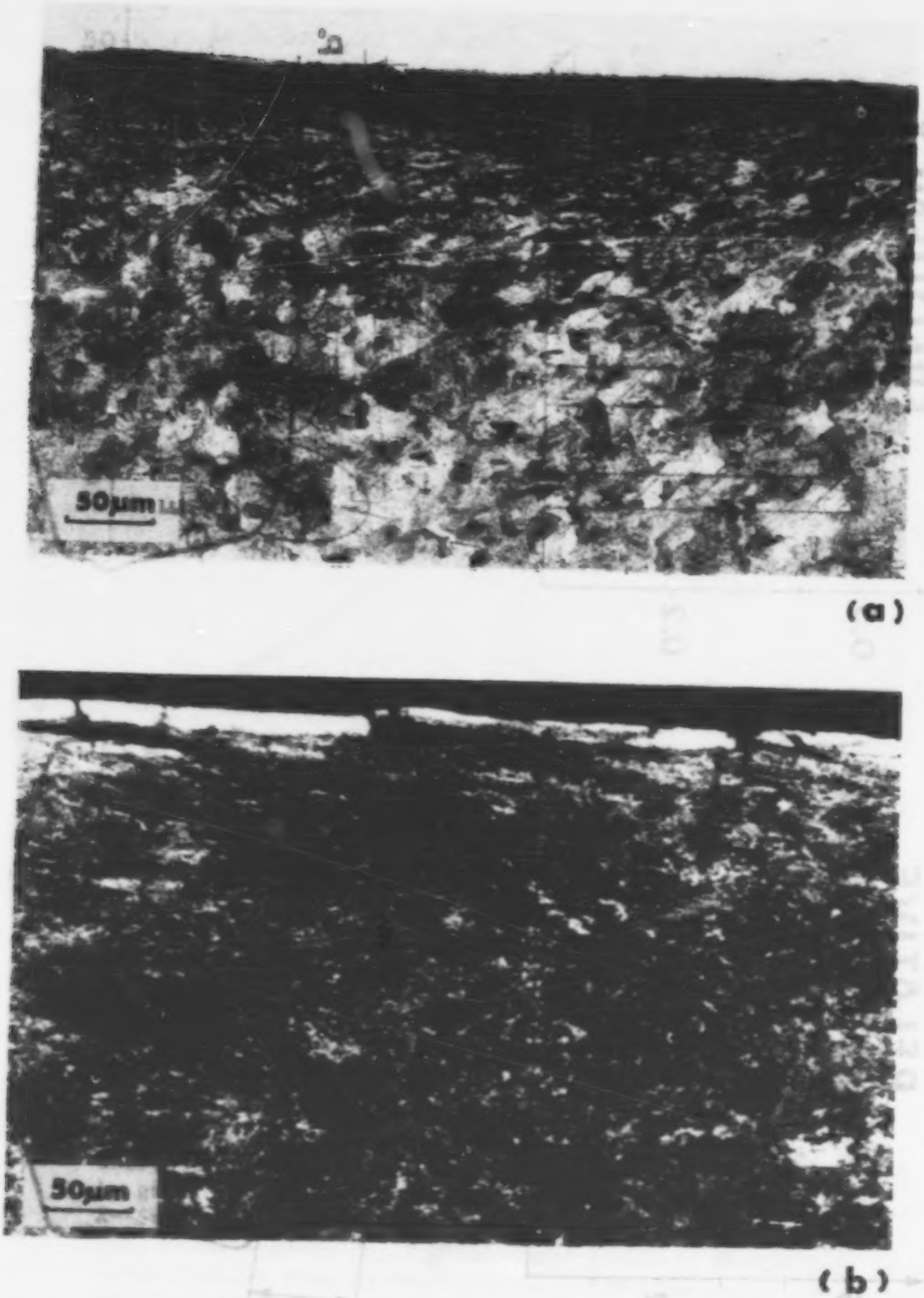


FIG. 3: Surface cracks formed by plastic instability of rail steel (a) gray etching work hardened steel above the crack (b) white etching particles above the crack.

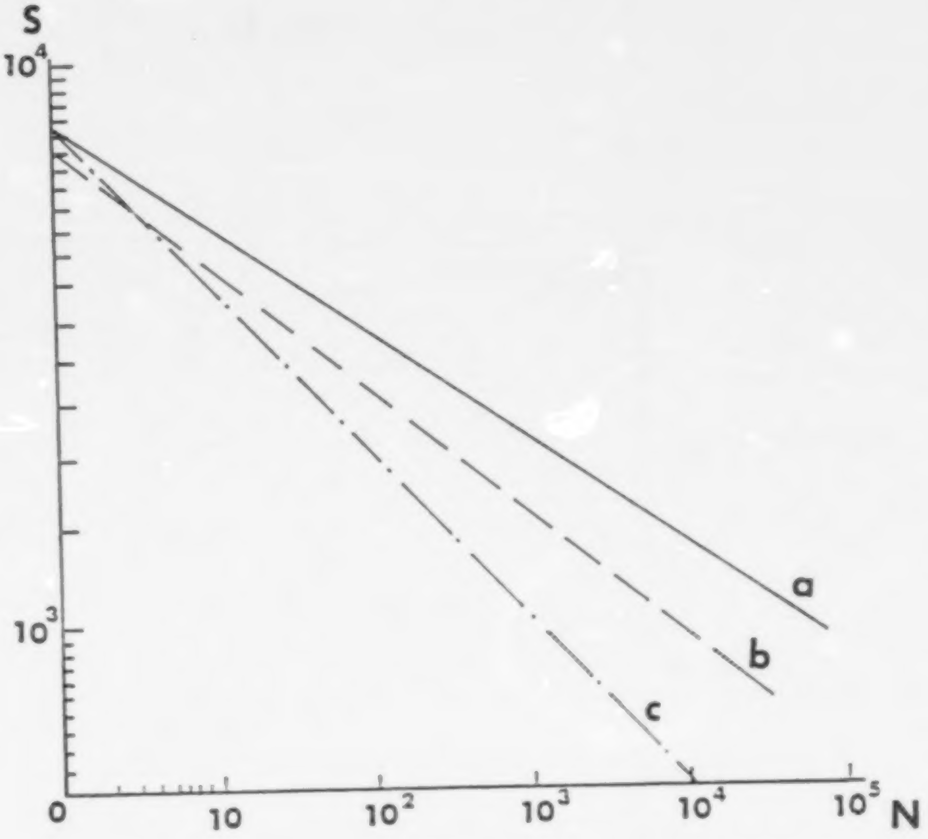


FIG. 4: S-N diagram for crack initiation by plastic instability for the coefficients of friction of (a) $\mu\approx0.1$, (b) $\mu\approx0.18$, (c) $\mu\approx0.3$. S--mean hertzian stress ($S\approx2/3p_0$), N--number of loading cycles.

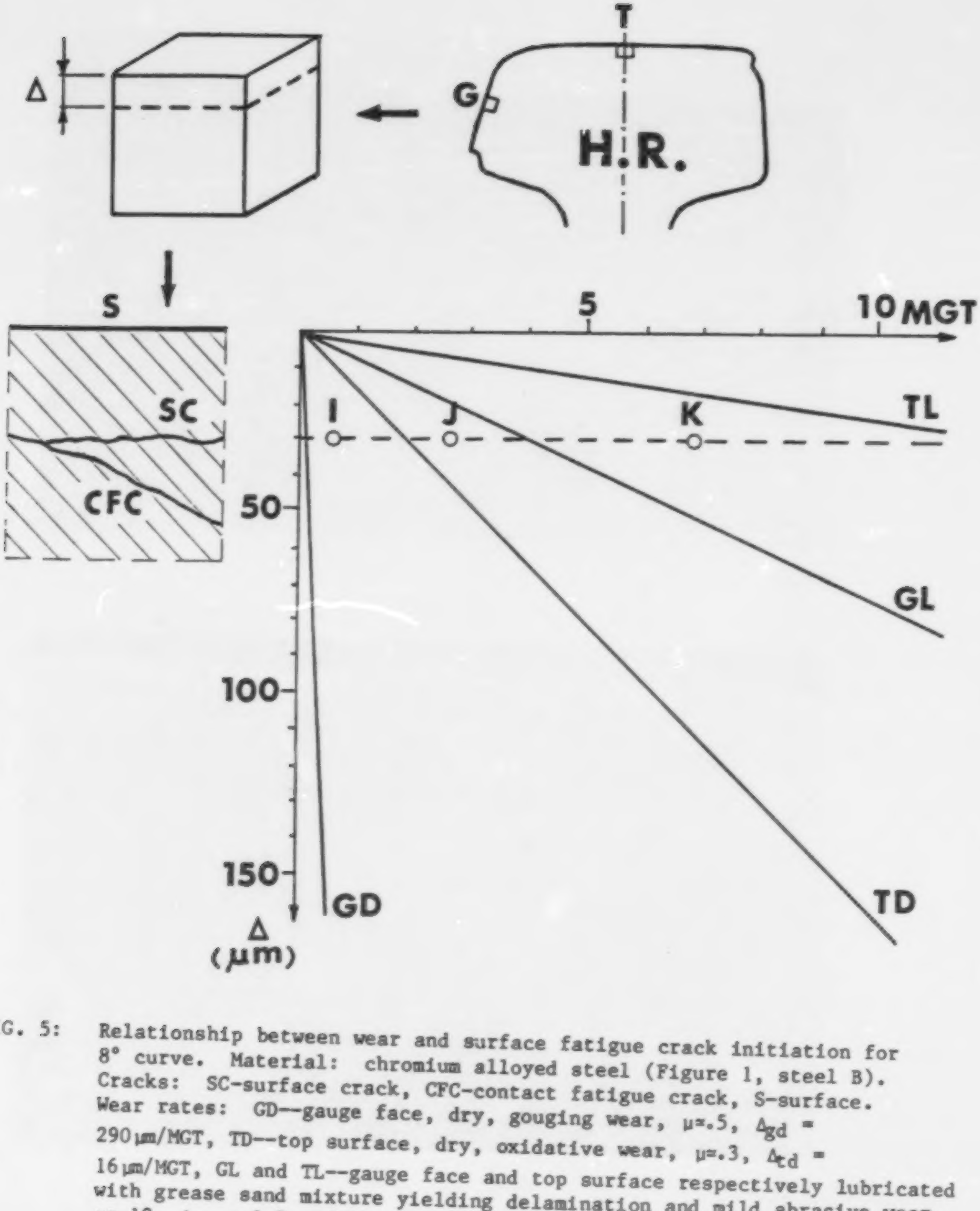


FIG. 5: Relationship between wear and surface fatigue crack initiation for 8° curve. Material: chromium alloyed steel (Figure 1, steel B). Cracks: SC-surface crack, CFC-contact fatigue crack, S-surface. Wear rates: GD--gauge face, dry, gouging wear, $\mu \approx .5$, $\Delta_{gd} = 290\,\mu m/MGT$, TD--top surface, dry, oxidative wear, $\mu \approx .3$, $\Delta_{td} = 16\,\mu m/MGT$, GL and TL--gauge face and top surface respectively lubricated with grease sand mixture yielding delamination and mild abrasive wear, $\mu \approx .18$, $\Delta_{gl} = 3.7\ \mu m/MGT$, $\Delta_{tl} = 2.4\ \mu m/MGT$. Surface crack initiation points: K--location B & C (Figure 2) lubricated by grease and sand, $\mu \approx .18$, J--location B & C, dry, $\mu \approx .3$, $p_0 = 1150MPa(167ksi)$, I--location A, lubricated by grease and sand, $\mu \approx .18$, $p_0 = 2,500MPa(363ksi)$.

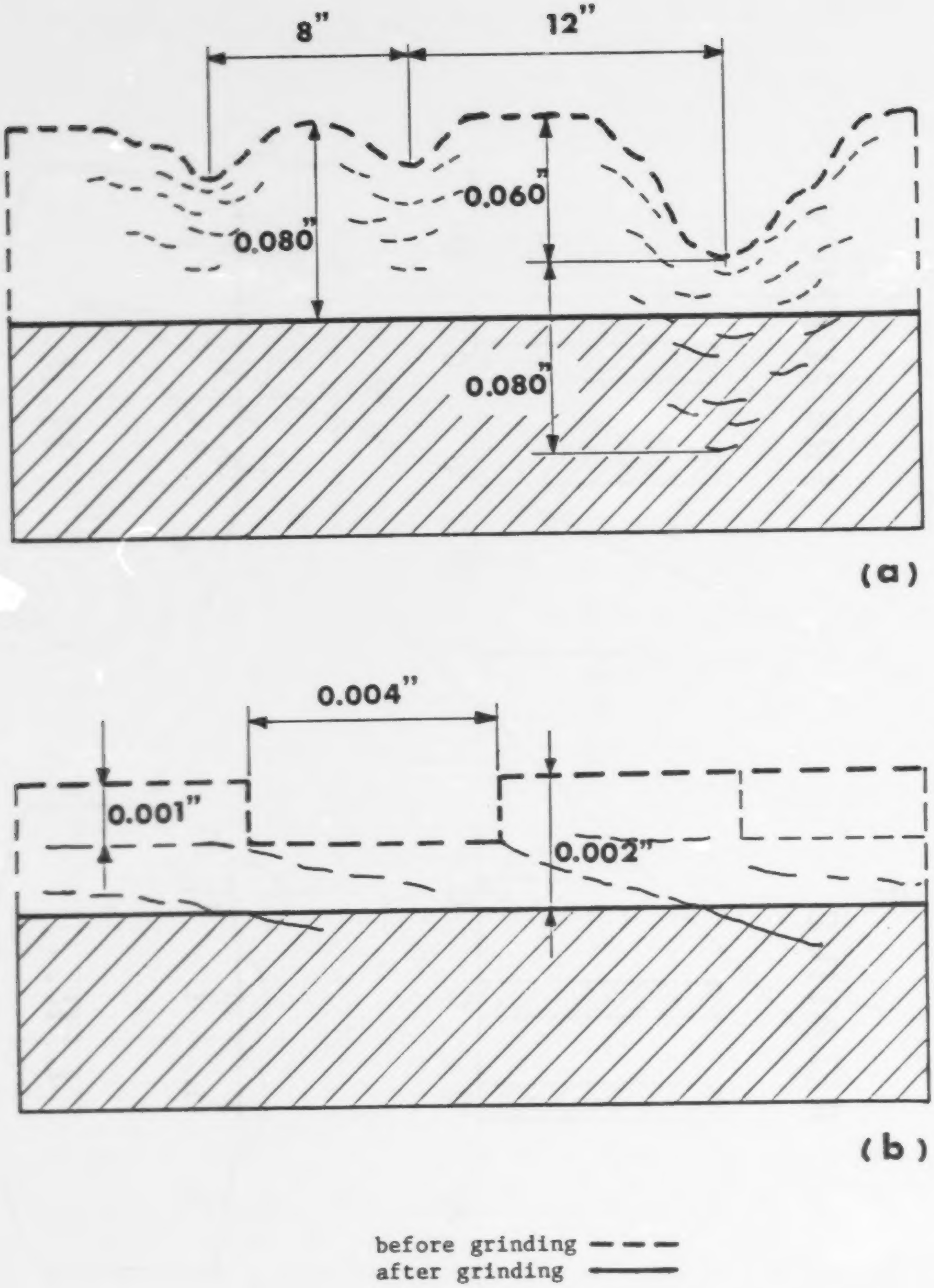

8"
12"
0.060"
0.080"
0.080"
(a)
0.004"
0.001"
0.002"
(b)
before grinding
after grinding

FIG. 6: Schematic of (a) corrective and (b) preventive grinding shown on (a) longitudinal and (b) transverse sections of railhead.

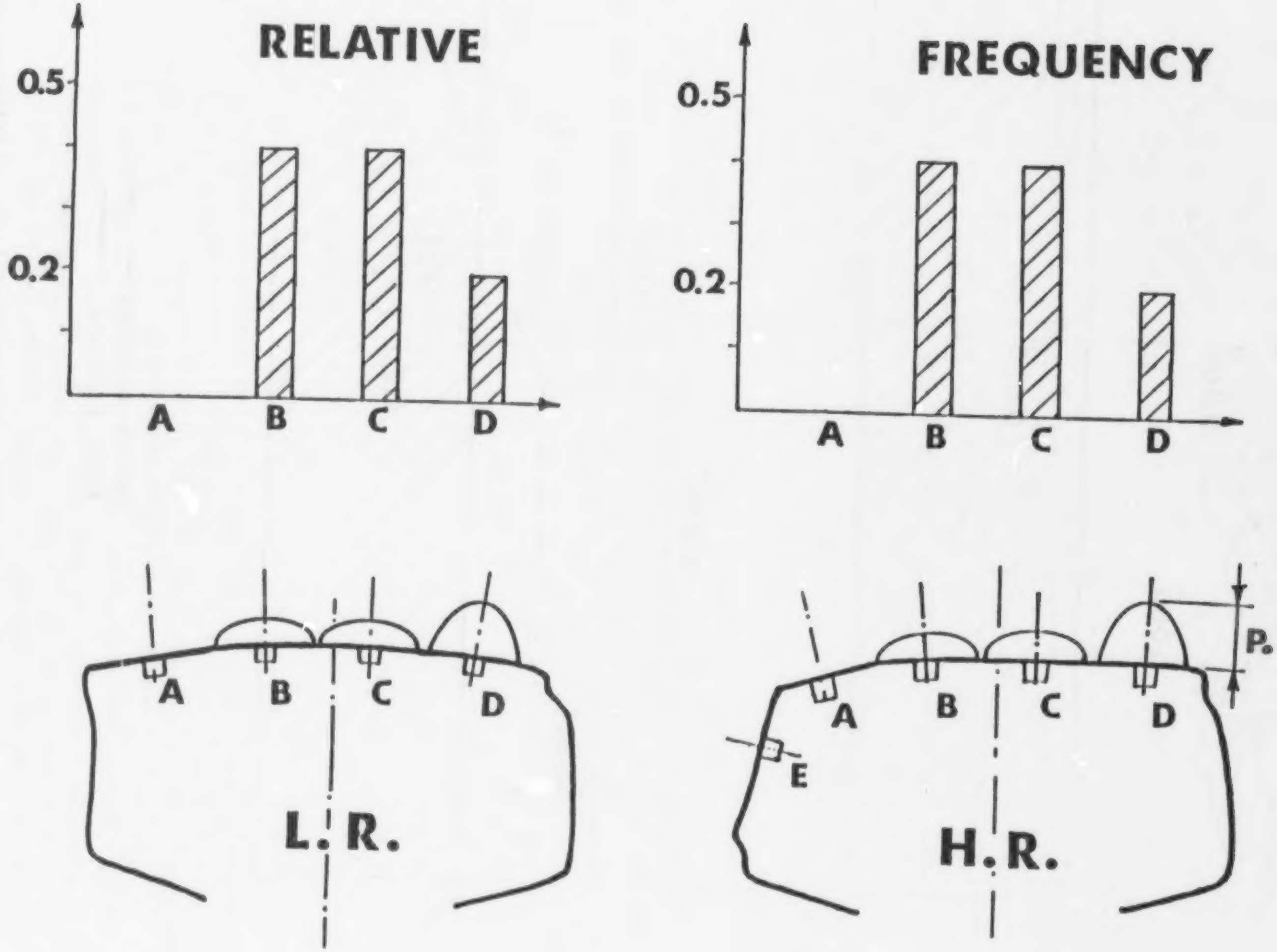


FIG. 7: Modified frequency histogram for preventively ground rails on 8° curve.

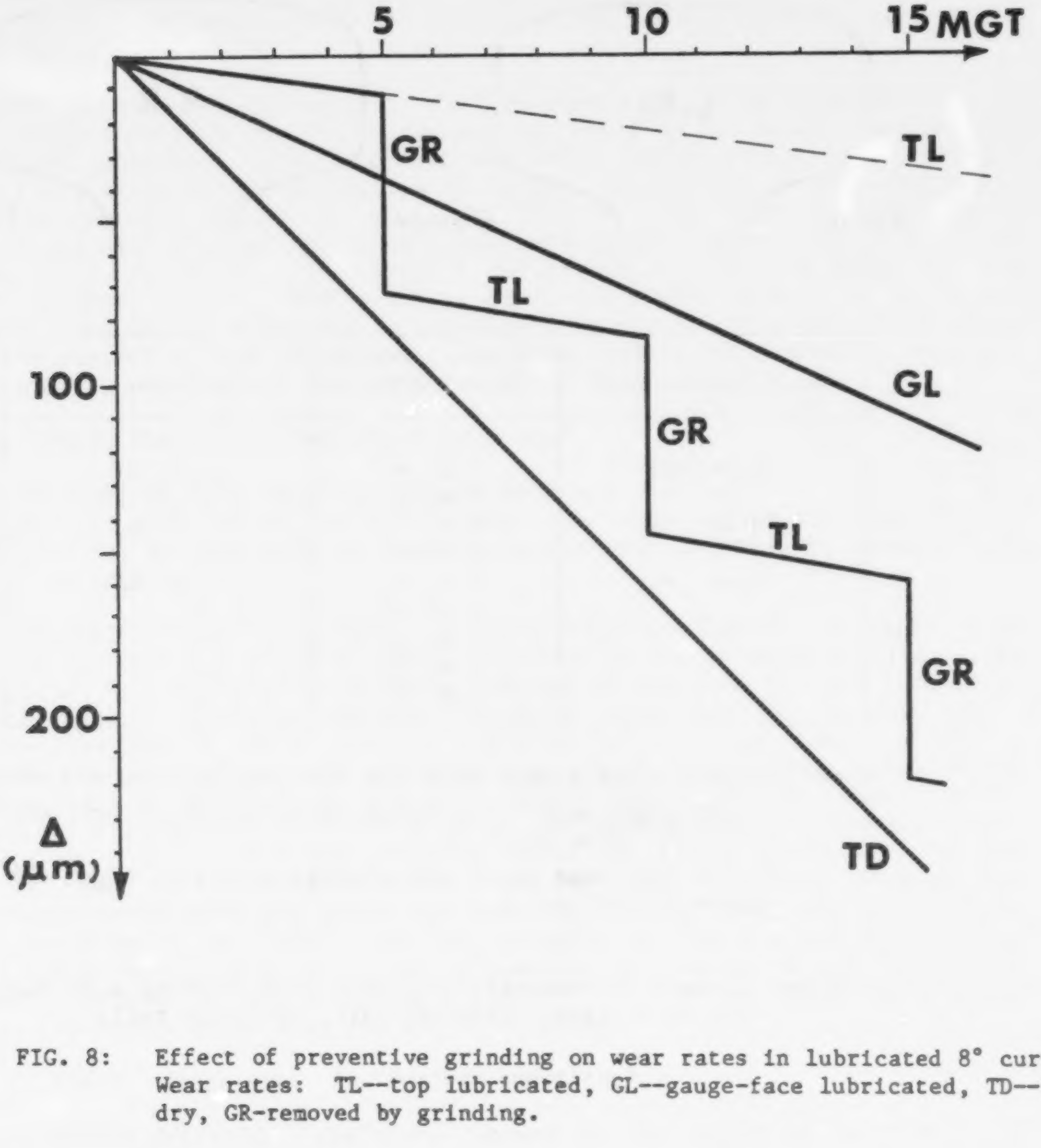
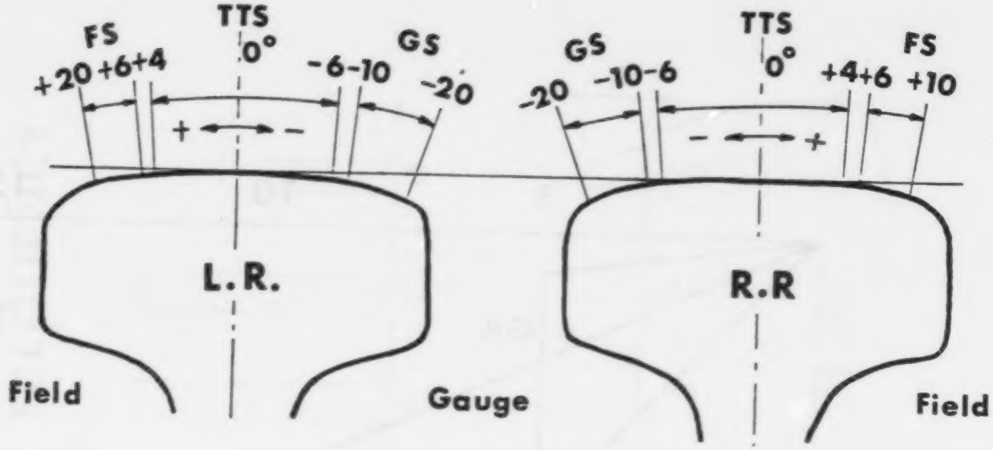


FIG. 8: Effect of preventive grinding on wear rates in lubricated 8° curve. Wear rates: TL--top lubricated, GL--gauge-face lubricated, TD--top dry, GR-removed by grinding.


FS
+20 +6+4
TTS
0°
GS
-6-10
-20
+
-
L.R.
Field
Gauge
GS
-20
-10-6
TTS
0°
FS
+4+6
+10
-
+
R.R
Field

| Field Stones (FS) | Tangent Track Stones (TTS) | Gauge Stones (GS) |
|---|---|---|
| 1 at +10<br>1 at +8<br>1 at +6 | 1 at +4<br>1 at +2<br>1 at +1<br>1 at 0<br>1 at -1<br>1 at -2<br>1 at -3<br>1 at -4<br>1 at -6 | 1 at -10<br>1 at -15<br>1 at -20 |

Note: -Tangent track stones grind all the time, including curves.

-In the right hand curve engage gauge stones on left and field stones on right rails.

-In the left hand curve engage gauge stones on right and field stones on left rails.

FIG. 9: Example of preventive grinding profile using a 30 stone grinding train. LR—left rail, RR—right rail.

## DISCUSSION ON
## PRESENTATION BY DR. J. KALOUSKEK

DR. R. W. SMITH (Queen's University): Could you comment on how good your scaling is. I think you said you had a one-tenth model; is that right?

DR. KALOUSEK: That is correct.

DR. SMITH: To what extent do you have equivalent data on full scale models?

DR. KALOUSEK: The correlations that we have done so far were mostly with the results obtained at "FAST", because it (Facility for Accelerated Service Testing), generates rather accurate wear data. With respect to metallurgy, the correlation is one to one. With respect to the size of wear particles, the correlation is one to one. So far, we have been very pleasantly surprised with what we can do on a one-tenth scale. Very few discrepancies have been observed. The biggest difference is in the depth of the work-hardened layer. That depth is about one-eighth of what it is in the field. And why it works out to one-eighth is due to the slight differences in the contact ellipse dimensions. The dimensions of my contact ellipse are not exactly one-tenth of the contact ellipse in the field.

M.D. RONEY (Chairman): Any other questions?

Let me take my chairman's privilege here and ask one. I think you are suggesting that if we go to tangent rail lubrication to reduce fuel consumption, we are going to have to do frequent grinding in tangent. Is that correct?

DR. KALOUSEK: That is correct. In my written version of this paper, I am proposing the exact grinding schedule as well as the grinding profile. I am proposing that the siding-to-siding section of track be divided into three subsections: (1) sharp curves, (2) mild curves and (3) tangent track. Every five MGT, a small grinding train having a minimum number of thirty stones per pass, would grind every sub-section of sharp curves, every second sub-section of mild curves and every third sub-section of tangent track. Thus, within each 10 or 15 MGT's the entire rail section, siding-to-siding, would be ground. This new grinding method would give a railway, for the first time, full control not only of the rail life, but also of the corrugations because you would not have any corrugations, and also control of the grinding policies. You can schedule it like airline maintenance. You don't have to wait till the corrugations are there and the roadmasters start fighting for the grinding train, or the fire marshall comes in and says you cannot grind now, and all those things.

M. D. RONEY: Thank you. Any further questions?

UNIDENTIFIED DELEGATE: Could you comment on the impact of lubrication on the potential benefit of increased adhesion through the use of shape memory alloys in wheel rims?

**DR. KALOUSEK:** Lubrication reduces the friction in rail/wheel interface and therefore would tend to negate the increase in adhesion that could be gained with the alloys.

# IMPROVED AUSTENITIC MANGANESE STEEL FOR RAILWAY APPLICATIONS

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## ABSTRACT

An improved austenitic manganese steel capable of giving longer life to such railroad components as frogs would be economically desirable. Work at Queen's over the last six years has been directed towards increasing the yield strength and wear resistance by minor alloy additions and variations in heat treatment. At the same time the capacity for work hardening and the excellent toughness of the original Hadfield's composition FE-13%Mn-1.2%C should not be drastically sacrificed. In addition, studies are continuing on weldability, response to explosive hardening and the screening of alloys by means of a specially designed impact-wear tester. It is intended that recently received funding from the Transportation Development Centre and CP Limited, will be utilized to study further variations in C content and small multi-alloy additions with their synergistic effect on mechanical properties which appear to have promise.

# IMPROVED AUSTENITIC MANGANESE STEEL FOR RAILWAY APPLICATIONS

## 1. INTRODUCTION:

Cast austenitic manganese steel is currently used for several railway applications; especially frogs and crossovers. An anticipated increase in traffic combined with higher axial loadings all lead towards increased wear and shortened life of these track components. This obviously results in increased costs in the case of frogs, for example, due to the expense of new and/or reconditioned frogs, installation costs and periodic in situ rebuilding by weld overlay. This entire picture is further complicated by the delay and inconvenience of track outage time.

The question is how do we go about improving the service life of this 100 year old type of steel? In summary we are attempting to obtain a compromise between improving the yield strength and wear resistance without appreciably departing from its most desirable existing properties of high impact strength and capacity for work hardening. This material must also possess acceptable weldability.

Queen's has been working on this problem since 1980 with varying degrees of intensity. The first large program was carried out on D.S.S. contract OST81-00116 (1981-1982) supported by Transport Canada. A further research program supported by CP and TDC has just been approved. This will enable us to continue the work of the previous program. In the intervening years between contracts, work has been carried out in certain areas by means of a Queen's University Research Council award and two BILD grants from the Province of Ontario. Thus this presentation is a status report rather than a progress report on current work.

## 2. APPROACH TO THE PROBLEM:

The initial approach to the problem was to reduce wear by the addition of carbide-forming elements. The idea was to obtain hard globular carbides suitably dispersed in the softer austenitic matrix of the steel. A somewhat similar approach is used in many types of tool steels. At the same time the carbide-forming additions will increase the "as solutionized" hardness (175-220 BHN) and yield strength (normally low at 200-400 MPa or 30,000 to 55,000 Psi) of the austenitic matrix thus reducing the tendency towards plastic deformation and resultant distortion of the running surface.

In order to maintain good toughness it is essential that an even dispersal of small carbides be achieved, avoiding anything approaching a continuous carbide network in the austenitic grain boundaries. This dispersal of carbides would have to be controlled by alloy additions and/or special heat treatments.

Consideration will also have to be given to other possible problems involving weldability, response to work hardening, foundry practice and heat treatment.

## TABLE 1

### The Nominal Chemical Composition of Experimental Alloys

| Alloy | Composition (%) (Balance Fe)<br>C | MN | V | Mo | Ni | Cu | W | Ti | Nb | Cr |
|---|---|---|---|---|---|---|---|---|---|---|
| R3[1] | 1.2 | 13 | --- | --- | --- | --- | --- | --- | --- | --- |
| R4 | 1.2 | 13 | 2 | --- | --- | --- | --- | --- | --- | --- |
| R5 | 1.2 | 13 | 2 | --- | 3 | --- | --- | --- | --- | --- |
| R6 | 0.8 | 13 | --- | --- | --- | --- | --- | --- | --- | --- |
| R7 | 0.8 | 13 | 2 | --- | --- | --- | --- | --- | --- | --- |
| R8 | 0.8 | 13 | 1 | 1 | --- | 1 | --- | --- | --- | --- |
| R9 | 0.8 | 13 | 1 | --- | --- | --- | --- | --- | --- | --- |
| R10 | 0.8 | 13 | --- | 1 | --- | --- | --- | --- | --- | --- |
| R11 | 0.8 | 13 | 1 | 1 | --- | --- | --- | --- | --- | --- |
| R12 | 0.8 | 13 | 1 | 1 | 3 | --- | --- | --- | --- | --- |
| R13 | 1.2 | 13 | 1.5 | --- | --- | --- | --- | --- | --- | --- |
| R14 | 0.8 | 13 | 0.7 | 0.7 | --- | 1 | --- | --- | --- | --- |
| R15 | 0.8 | 13 | 1 | --- | 3 | --- | --- | --- | --- | --- |
| R16 | 1.2 | 13 | --- | --- | --- | --- | 2 | --- | --- | --- |
| R17 | 1.2 | 13 | 0.7 | --- | --- | --- | --- | .7 | .7 | --- |
| R18 | 1.2 | 13 | .3 | 1 | --- | --- | --- | .3 | .3 | 2 |
| R19 | 1.2 | 13 | --- | 1 | --- | --- | 2 | --- | --- | 2 |

[1] Standard Hadfield alloy used as reference alloy.

## 3. MECHANICAL TEST RESULTS:

The nominal chemical analyses of the last series cast (R series) is given in Table 1.

Abrasive wear tests were carried out on alloys R3 to R8. They indicated that the 1.2%C rather than the 0.8%C and the presence of V gave improved wear resistance. As adhesive rather than abrasive wear is much more important in the applications being considered the results are not included.

Compressive yield strength tests on alloys R3 to R15 are shown in Table 2. The effectiveness of V is noticeable.

Table 3 shows results of impact and hardness testing. A wide variation in toughness was evident. Alloys R14, R16 and R19 appear attractive for further investigation due to their combination of high compressive yield strengths and toughness.

Starting with the reference alloy R3 (standard Hadfields analysis) the principal alloyng element added initialy was V. Later work combined it with Mo and then other elements. Improved properties were obtained by a synergistic effect from minor multi-alloy additions. Work to-date has not indicated much improvement by additions of Ni. The role of Cu as a carbide refiner and its reported action in maintaining a discontinuous distribution of carbides is still in question. Our first attempt to control grain size

## TABLE 2

### Compressive Yield Strength of Experimental Alloys

| Alloy | Yield Strength MPa (Heat to 1050°C and W.Q.) |
|---|---|
| R3[2] | 319 |
| R4 | 346 |
| R5 | 325 |
| R6[1] | 263 |
| R7[1] | 350 |
| R8[1] | 460 |
| R9[1] | 297 |
| R10[1] | 289 |
| R11[1] | 312 |
| R12[1] | 290 |
| R13 | 329 |
| R14[1] | 288 |
| R15[1] | 341 |

[1] All alloys were lower C (0.8%)

[2] Standard Hadfield reference alloy

## TABLE 3

## TOUGHNESS (N-m) AND HARDNESS VALUES (BHN)

| ALLOY | IZOD 1050°C 2 hrs 600°C 6 hrs | IZOD 1150°C 2 hrs | CHARPY 1150°C 2 hrs | CHARPY As cast | HARDNESS BHN (3000 Kg) |
|---|---|---|---|---|---|
| R3 | 148 | 163 | 285 | | 159 |
| | | | (26)$^{1\&3}$ | | |
| R4 | 16 | 15 | 24 | (7)$^{1\&3}$ | 248 |
| | | | (39)$^{2\&3}$ | | |
| R5 | 28 | 23 | 30 | | 229 |
| R6 | 156 | 154 | 217 | | 179 |
| R7 | 34 | 27 | 39 | | 255 |
| R8 | 68 | 68 | 84 (122)$^{3}$ | | 192 (167)$^{3}$ |
| R9 | | | 81 | | 179 |
| R10 | | | 230 | | 149 |
| R11 | | | 88 | | 192 |
| R12 | | | 92 | | 179 |
| R13 | | | 41 | | 192 |
| R14 | | | 136 (122)$^{3}$ | | 167 (143)$^{3}$ |
| R15 | | | 81 | | 179 |
| R16 | | | 203 | | 156 |
| R17 | | | 42 | | 179 |
| R18 | | | 61 | | 197 |
| R19 | | | 126 | | 170 |

1: Samples were cast without $N_2$ gas bubbled through.

2: Sample was cast with $N_2$ gas bubbled through.

3: Heat-treated (invacuum) to 1150°C for 10 hrs and water-quenched.

with a Nb and Ti addition in alloy R18 was successful. The alloy addition which produced remarkable combination of properties was W as shown in alloys R16 and R19.

## 4. OTHER AREAS REQUIRING FURTHER RESEARCH:

An improved alloy will not result alone from the casting of different alloys and evaluating them by mechanical means. Information is required on various items in order to develope the best composition and processing practice. Some of these items which require further work are as follows:

Grain Size Control - Further work required to obtain optimum additions.

Residuals - For example what level of P can be tolerated and will this demand a change in melting practice.

Decarburization - This may require controlled atmosphere heating especially for items of small cross section.

Thermal Analysis, Constitution Diagrams and TTT Curves - Information is required for heat treating.

Weldability - Preliminary tests indicate that present CP frog repair practice does not result in over-heating and that presently used welding rods may be improved.

Explosive Hardening - Only tests on small experimental specimens have been carried out.

Wear-Impact Simulator (Timpact Machine) - To-date mechanical properties have been determined by conventional tests. This has not been entirely satisfactory. The Timpact machine combines adhesive wear and impact at loadings which simulate to some degree the effect of a wheel contacting the frog point. This machine is intended as a realistic screening device and gives numerical information as to work hardening and deformation.

In conclusion, research alone cannot contribute to an improved austenitic manganese steel without good processing practice and quality control with all concerned treating these railway components as premium products.

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## DISCUSSION ON
## PRESENTATION BY DR. W.B.F. MACKAY

UNIDENTIFIED DELEGATE: Was there any specific plan to determine the correct combination of the various elements?

DR. MACKAY: Well, 1.2% carbon is the original Hadfield's reference alloy and we were afraid at first to reduce that because we thought that the work hardening capacity would fall away. However, we were inclined to check it anyway because other people in the United Kingdom and elsewhere had looked at that. We were afraid of weldability and we were trying to keep the carbon down in order to improve the weldability because we did not want carbides forming a carbide network after welding. Now we are trying to take the opposite approach where we think, for yield and wear, we need the higher carbon. We are not quite as worried as we were at one time as to the weldability.

UNIDENTIFIED DELEGATE: I am a bit curious about the Niobium additions because such small amounts are added in high strength low alloy steels, and you have 0.3% and 0.7% and although the solubility of the Niobium carbide is much more, I was just wondering what sort of Niobium carbide you have got in this particular steel?

DR. MACKAY: The point was that on that alloy they added the two together (Titanium and Niobium), which I was not happy about. R-18 is the one we had some luck with; that is the 0.3%, the smaller addition. I think they were getting down. Those additions may even be high. I think that actually about 0.2% Titanium would be sufficient to do it, without putting the two of them in together.

UNIDENTIFIED DELEGATE: What was the effect of the addition of those two alloys on the impact strength?

DR. MACKAY: R-19 was not too bad; that was 126. The impact strength was poor on both R17 and R18; however, I don't think it was necessarily because of the grain refining addition. It was the other stuff we had in there. There were too many variables in that particular alloy. The impacts were low - 42 and 61. We have done additions of much higher Niobium and it did not show any appreciable gain at all as a large alloying element. However, I think it may have merit in smaller amounts as a grain refiner. We did get a much refined grain size with the 0.3% additions.

R. W. SMITH (Queen's University): Could I just add one point. Part of this was concerned with attempting to evaluate some reference work.

M. D. RONEY (Chairman): I have a question. There is a concern that you have so many possible combinations in the work that quality control might be another variable that would enter the picture. What are you doing to try to proceed in a step-wise manner?

DR. MACKAY: Well some of the data does not show a logical approach. We have run other tests on Vanadium and on Niobium under controlled conditions to get a feel as to which way we were going. But you are quite right. I won't say we are "shot gunning" the field but to some extent this chart looks like it. There is no way of sitting down and doing this mathematically, and quoting Decker who used to be with International Nickel, we are trying to use "enlightened empiricism".

M. D. RONEY: Thank you very much. Very interesting.

# FULL-SCALE WHEEL/RAIL TEST FACILITY

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## ABSTRACT

The design and build of a facility capable of testing a full-scale, standard gauge wheelset and associated brake rigging is being undertaken by the National Research Council (NRC) with partial funding by TDC. The facility is to be capable of extended duration wear tests (i.e. of a month or more duration) and the testing of wheelset components (brakes, wheels, bearings and axles) under controlled, yet realistic, environmental conditions. The facility will be unique in that it is to simulate, at full-scale, both the rail/wheel and brake/wheel interface while allowing for control of temperature and introduction of contaminants.

The facility will use two driven rollers to simulate rails and will consist of a double frame wherein the flexure-mounted inner frame can move relative to a stiff outer frame. Such flexure mounting allows for positioning of the wheelset relative to the rollers and for incorporation of load cells to measure the relevant force components at each roller. The wheelset will be positioned using ball screws and vertically loaded using hydraulic actuators.

The configuration represents an attempt to simulate, as accurately as possible, actual wheel/rail contact conditions without compromising mechanical simplicity or operating reliability.

The facility is to be located at the NRC Vehicle Dynamics Laboratory, Ottawa, with access to the recently commissioned NRC Environmental Chamber, and is to be available for use by the railway industry and for in-house research.

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The design and build of a facility capable of testing a full-scale, standard gauge wheelset and associated brake rigging is being undertaken by the National Research Council with partial funding by Transport Development Centre of Transport Canada. The facility is to be capable of extended duration wear tests (i.e. of a month or more duration) and the testing of wheelset components (brakes, wheels, bearings and axles) under controlled, yet realistic, environmental conditions. The facility will be unique in that it is to simulate, at full-scale, both the rail/wheel and brake/wheel interface, while allowing for control of temperature and introduction of contaminants. The facility is to be located at the Vehicle Dynamics Laboratory, NRC, Ottawa, with access to the recently commissioned NRC Environmental Chamber and is to be available for use by the Railway Industry and for in-house research.

This paper provides a brief overview of the program including possible applications for the facility, and its configuration and limitations. The detailed technical aspects of the program are covered in References 1 and 2.

## WHEEL/RAIL SYSTEM

The wheel/rail system provides vertical support, longitudinal traction (and braking), and lateral guidance to railway vehicles in the presence of various contaminants and over an extended temperature range. Guidance forces in wheel/rail systems are produced by the interaction of coned wheels running on canted rails, through a contact area of approximately a quarter of a square inch per wheel.

Under field conditions, freight car wheelsets may operate to speeds of 80 mph (130 kph) in the presence of contaminants such as oil, grease, sand, water and various wear particles from wheels, rails and brakes, while being exposed to extremes of temperature ranging from -50°F to 110°F (-45°C to 45°C) in the presence of ice, snow and/or rain. In the field the possible range and combination of conditions is virtually infinite such that it is virtually impossible to obtain data under "controlled conditions". Testing under field conditions is expensive and time-consuming and field data typically exhibits considerable scatter.

## POTENTIAL APPLICATIONS AND ASSOCIATED REQUIREMENTS

The major applications on which the design has been based, may be considered to be wear, investigation of mechanical components and investigation of wheel/rail interaction.

- wear

  Rail and wheel wear costs Canadian railways in the order of $500 million per year, with approximately 70% on rail and 30% on wheels. Any study of wheel or rail wear requires a reproduction of all factors affecting wear - both at the wheel/rail interface (adhesive wear) and at the wheel/brake interface (abrasive wear).

- mechanical components

  The mechanical components of a wheelset on which testing may be required are the wheels, axles, and bearings as well as the associated brakes and brake rigging. Such tests might include determination of braking effectiveness, wheel stress distribution, axle stress distribution or bearing performance, under various conditions of temperature and/or contaminants.

- wheel/rail interaction

  Ultimately, what occurs in the wheel/rail contact zone determines wear and stability and investigation of this basic phenomenon will hopefully lead to a better understanding of the wear process and to a better understanding, and modelling, of wheel/rail interaction.

For a facility to be capable of such tests it should, in general terms:

- accurately simulate the wheel/rail contact phenomena of the field in terms of equivalent speed, equivalent load and equivalent wheel/rail positions such that equivalent wheel/rail contact areas and stress distributions are produced;

- accommodate typical wheelsets (28-44" dia.) and their associated bearings and brake rigging (tread, clasp or possibly disc brakes);

- duplicate field conditions in terms of presence of lubricants and/or contaminants as well as extremes of temperature;

- have variable inertia such that one-quarter of the inertia of any car ranging from an empty vehicle to a loaded 125-T can can be readily simulated;

- have provision for controlling and/or monitoring all relevant parameters including speed, loads, wheelset position, and temperature.

During the design phase, emphasis has been on incorporating as much of the above as current economic restraints permit, while providing for subsequent reconfigurations as may be required. On this basis, no inertia will be incorporated in the initial build, although the facility is being designed such that inertia can be subsequently incorporated, when demonstrated need exists and/or economics permit.

## FACILITY CONFIGURATION

The facility configuration has been evolved by NRC personnel and through discussion with the Steering Committee on Full-Scale Multipurpose Wheel/Rail System Testing. Basically the facility must simulate, as accurately as possible, actual wheel/rail contact forces without seriously compromising mechanical simplicity and operating reliability. It is to use rollers to simulate rails, as shown schematically in Figure 1. In its most simple form the facility may be considered to consist of a load frame, a driveline and a flexibly mounted overhead table such that a wheelset (and associated brake rigging) can be appropriately positioned above a set of rollers (which may be rotated) and representative loads and positions applied to the wheelset. Each roller is to be instrumented such that the vertical, lateral, longitudinal and spin moment components transmitted by each wheel can be separately measured.

A side-by-side placement of the wheelset and rollers was considered since, in some ways, it is mechanically simpler than the selected wheelset-over-roller configuration. However, the side-by-side configuration was rejected since the rig width would become excessive and since accurate simulation of the required forces at the wheel/rail interface would become difficult. Similarly, a configuration locating the rollers above the wheelset, which would provide for a cleaner driveline location, was rejected on the basis of the difficulty of providing a stable base for the drive system and its associated inertia, and of correctly simulating the actual wheel/rail forces. Thus a wheelset-over-roller configuration was chosen on the basis that it appeared to offer the best potential for providing a stable base for the drive system and for simulation of the wheel/rail interface in terms of contact area and stress distribution.

The proposed configuration represents a compromise between an overly simplified facility, which would be of limited practical usefulness, and an overly sophisticated facility, which would be very expensive and on which parameter control would become very difficult. Herein emphasis has been on simplicity and ruggedness, such that the facility will be suitable for extended duration tests in the presence of contaminants and such that the facility may be reconfigurated if subsequently required.

### Inherent Limitations

It is impossible to exactly duplicate the wheel/rail interface with any facility, even using a full-scale wheelset and thus it is important to be aware of the inherent limitations, the major of which may be considered to be:

- elements for which simulation is not attempted.
  In order to maintain rig simplicity and ruggedness at reasonable cost, no provision is to be made for wheelset suspension components, dynamic track inputs or roller differential speed.

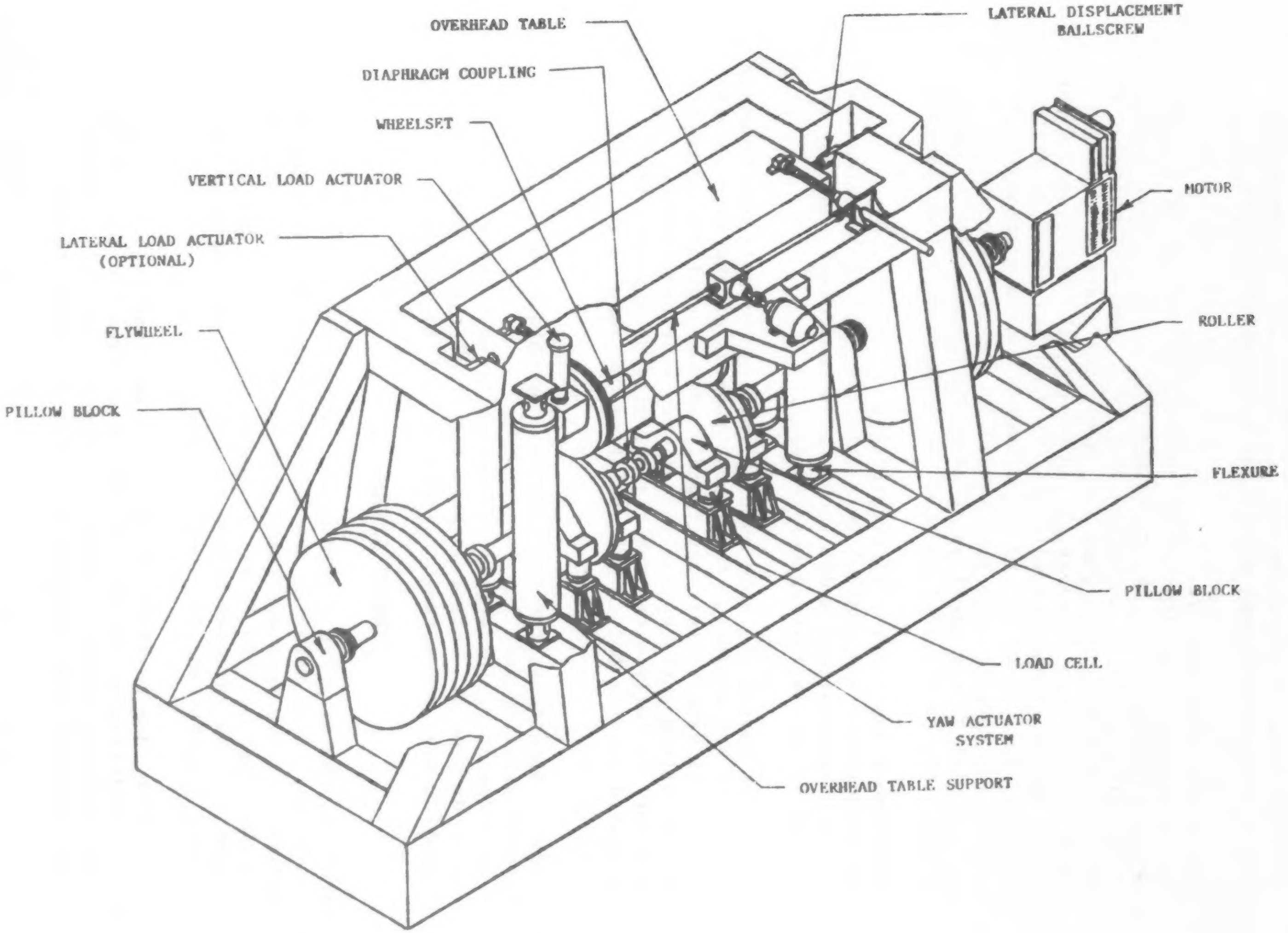
OVERHEAD TABLE
DIAPHRAGM COUPLING
WHEELSET
VERTICAL LOAD ACTUATOR
LATERAL LOAD ACTUATOR (OPTIONAL)
FLYWHEEL
PILLOW BLOCK
LATERAL DISPLACEMENT BALLSCREW
MOTOR
ROLLER
FLEXURE
PILLOW BLOCK
LOAD CELL
YAW ACTUATOR SYSTEM
OVERHEAD TABLE SUPPORT

FIGURE 1

ISOMETRIC OF PROPOSED RIG CONFIGURATION

Further, in the initial build, no inertia will be provided although there is provision for its subsequent incorporation - when a demonstrated need exists and/or economics permit

- simulation inaccuracies.
  The major simulation inaccuracy arises from the use of a roller having a finite radius of curvature to simulate a rail having an infinite radius of curvature such that some decrowning of the wheelset occurs, except when the wheels are exactly centered above the rollers. However, if necessary, the magnitude of this effect may be characterized since the facility has been designed such that rollers of 51" to 72" diameter can be accomodated. Further inaccuracies are also caused by the use of uncanted rollers with tilted profiles to simulate canted rails. However, if required, canted rollers could be subsequently incorporated.

- measurement and control uncertainties.
  The measurement and control uncertainties are to be accounted for in a mathematical model such that a confidence band may be applied to all facility-generated data.

- effects of having the same pair of rolling surfaces continuously exposed to one another. Continuous running of the same wheels against the same rollers may rapidly produce conformal geometry of the rolling surfaces and unrealistic wear conditions. It is necessary to fully establish the validity of any facility-generated results before extrapolating new results to field conditions.

Despite these limitations, the facility will be unique in simultaneously allowing for

- measurement of the wheel/rail forces at each wheel
- introduction of contaminants to the wheel/roller interface
- testing over a temperature range of -30° to +45°C.

## CURRENT STATUS

Currently, the detailed design phase, being done in-house at NRC, is well underway. Some material and components have been ordered and some received. It has been estimated that machining and assembly will require in the order of 8-10 PY's. Following this phase, balancing and commissioning will be required before the facility is available for use by the railway industry and for in-house research.

At this time, due to financial and manpower constraints, it is not possible to realistically estimate a completion date for the initial build of the facility (without inertia); however, possible avenues for reducing the calendar time required are currently under review.

## REFERENCES

1. Tucker, H.G. "Proposal for a full-scale multipurpose wheel/rail test facility", National Research Council Report, TR-RW-002, Ottawa, July 1984.

2. Tucker, H.G. "Design specifications and acceptance tests for a full-scale multipurpose wheel/rail facility", National Research Council Report, TR-RW-005, Ottawa, April 1985.

# DISCUSSION ON
# PRESENTATION BY H. G. TUCKER

F. B. BLADER (Consultant): Could I ask Helen if she could tell us a little bit about what might be happening to analyze the rig and of what the status is in the analysis? I personally would like to lay emphasis on the fact that one ought to have an accompanying analysis and simulation.

H. G. TUCKER: I entirely agree with you and it is something that should have been done right from the beginning, but if we look at the in-house effort to date, I have been around the project since about 1982 and had an assistant for only about 8 months. Basically it is only my time on the project and I guess my talents don't lie on that side and I probably have not done enough on it.

Specifically though, we have had the framing analyzed and we have identified the modes of the frames that might be a problem, that might come into our operating range. We did some redesign on the frame to ensure that we don't have resonances down in the operating range and we are planning to do a modal analysis on the frame, to check that analysis and if we do have problems, to sort them out before we install the drive line.

F. B. BLADER: I was thinking more of analysis with regards to the wheel/rail modelling and that sort of thing.

H. G. TUCKER: Yes, and again when we get into it, this should draw on the expertise of some of our in-house people who have done some of that modelling, but I think what you are suggesting is not just the contact area, but what effect is this rig having on what is going on in that contact area.

F. B. BLADER: For example, it would be impossible for one to easily vary the wheel/rail profiles and put in all sorts of combinations and variations you get from that source in the real world, but it is possible to do that sort of extrapolation, if you will, through an accompanying analysis. And I think that it is very important to have such an analysis going hand-in-hand with the development of the rig.

H. G. TUCKER: I agree with you. To the extent that you are talking about varying profiles, this was one thing I did not mention and should have, because Joe Kalousek was down to see us in April, and one of the things we are currently looking at is where can we put a re-profiler, putting framing in so that we could reprofile the roller on the run like Joe was interested in. Also, how do we put in framing and how do we drive the wheelset when it is in the upper position so that we can in fact re-profile the wheels on the rig itself?

UNIDENTIFIED DELEGATE: I gather that if, in fact, you use a straight line, and all the line is welded, then really you don't have too many problems with whatever it is that is running on the line.. The main problem tends to be curves and the sharper the curve, the greater the problem. Why did you elect not to, other than simply expense, choose to differentially guide the two rollers so that you can get some interaction here?

H. G. TUCKER: I think that is a very legitimate question. We already have in-house, a curved track simulator that is under way. This would, in fact, simulate curving in terms of moving the rollers to give you the curves and putting a differential motor between the two rollers so you have the differential speed that gives you the difference in length as you go around curves. This rig was a simpler version that we can beat about with things like long term wear tests and if you want to get into curving, one thing that you can do on it, without going into the complexity of the differential speed, is to go to a slight difference in diameter. It is not very much and you can, in fact, look at curving that way. Do you wish to say anything more on that Joe?

J. KALOUSEK (NRC): All I want to say is that in dynamic phenomena, especially in mild curves, both the differential in rolling radii on the wheelset, and the difference in length of outer rail as opposed to inner rail, are both important. But in this facility, where we are generating a sharp curve, the effect of creepage decreases and is not as important as in the dynamic study.

UNIDENTIFIED DELEGATE: Out of curiosity, what is this going to cost?

J. PLOEG (NRC): The cost arrangement at the moment is $300,000 from TDC for buying the hardware, with NRC providing a share of the hardware plus in-house costs. The cost of manufacturing the rig will be borne by NRC with help from some of the users. The total projected cost is $600,000.

[illegible] curves on the charts: the curves, the greater the gradient. [illegible]

[illegible] I think that is a very legitimate question. [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

# TRACK RESEARCH PROGRAM
# AN OVERVIEW OF CURRENT STATUS

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## ABSTRACT

The track research program centres on i) component improvement and ii) track system modelling. The focus of component improvement has been geotextile, subballast, tie and rail. The focus of track system modelling has been technical validity and ease of application.

Achievements in the first area include: a) a comprehensive manual on geotextile selection and application; b) a detailed guideline on track design with or without geotextile for a range of existing subballast materials; c) a better understanding of wood tie degradation that would lead to techniques for improving tie performance; d) an optimal rail profile which reduces existing rail corrugation and fatigue problems.

Achievements in the second area include: a) a track system model consisting of four modules - vehicle dynamics, rail life, tie life, surfacing and lining cycle; b) a data acquisition and analysis system which permits the recording of track dynamic and permanent settlement as well as track geometry error growth; c) a set of vehicle/track dynamic interaction computer simulation models which permit a wide range of dynamic track force analyses; d) a comprehensive analysis of track maintenance on an operating railroad.

# TRACK RESEARCH PROGRAM

## AN OVERVIEW OF CURRENT STATUS

## 1. INTRODUCTION

Canadian railways have experienced a rapid increase in traffic growth during the last two decades. This increase has been accommodated by a large increase in axle loads, train speeds and train lengths, as well as some modest track capacity expansionary construction. On some of the most heavily loaded lines, the railways have made significant investments in track upgrading to offset accelerated wear rates.

It is expected that traffic growth will continue. This creates demand for further increases in axle loads, train lengths and traffic density, since track capacity expansionary construction is very costly. The Australian iron ore railways recently experimented with a train length of 230 cars, an axle load of 35 tonnes and a speed of 85 km/h. In North America there has been a great deal of contemplation about using 125-ton cars (approximately 35 tonnes axle load) for freight traffic and a speed of 200 km/h (125 mph) for passenger traffic. Rail, tie wear and track geometry deterioration are likely to increase, creating a greater requirement for track maintenance, precisely when less track occupancy time for maintenance can be made available.

Tighter operating conditions and increasing competitiveness among North American railroads has led to the need for more effective management tools to aid in the decision-making process. For a long time railroads have used computer technology to develop extensive data bases on track performance. Information is now available on the degradation history and current status of track components and geometry. Information is also available on the related traffic characteristics. A computer program which links traffic to track degradation would be very helpful in assisting the railroads to make better use of available information. With the recent development of microcomputers, such tools can now be used not only by head office management but also by local track maintenance managers to improve the overall productivity.

The Transportation Development Centre of Transport Canada has sponsored a three-year government/industry cooperative track system research program aimed at developing (a) practical and cost-effective techniques to reduce track geometry and component deterioration, and (b) a systematic approach to track maintenance planning to improve cost and time efficiency. At the same time, the program also aims to foster basic track support and structure research to ensure the researcher's long-term ability to support track maintenance innovations.

Railway industry support was provided by CN Rail, CP Rail, and the Association of American Railroads, either as direct or parallel project support.

This outline outlines the achievements of the program to date and desirable future research work.

## 2. PROGRESS IN TRACK COMPONENT IMPROVEMENT RESEARCH

The principal achievements of the track component research program to date are specifications and design guidelines for effective application of geotextiles and subballast in track structure construction and rehabilitation.

The geotextile specifications cover not only the desirable material properties but also the procedure and apparatus used in qualification testing and the manufacturing process which can yield the basic required properties. The design guidelines for geotextiles cover installation procedures and track locations where geotextiles will offer the greatest improvement potential.

The specification on subballast covers track design options with and without geotextiles. Together with earlier comprehensive research on ballast which led to the development of modern ballast specifications at CN and CP, recent work provides the basis for significant improvement in the design and construction of the track support structure. A comprehensive report on the subject has been produced by the principal researcher, Dr. G.P. Raymond of Queen's University in Kingston.[1]

In addition to research on track support, two other parallel research programs at CIGGT deserve mention. One concerns rail profile grinding, the other tie/fastener systems.

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[1] "Subballast and Geotextiles for Track Support Separation Applications," G.P. Raymond, CIGGT Report No. 85-12, December 1985.

The rail profile grinding research program,[2] under way since 1981, has resulted in new ground rail profile specifications which, as indicated by field trial data, could save significant rail costs. This program is now moving into the third phase which concentrates on practical procedures to extract the most benefit from the new grinding technique.

The tie/fastener system program,[3] in progress since 1985, examines the degradation process of wood ties and the merits of changing to concrete or steel ties. Results of work to date have identified a number of improvements which could significantly extend the life and performance quality of wood ties. The cost/performance trade-offs of steel and concrete ties were analyzed. This program is now moving into the second phase which concentrates on the influence of fastening system elasticity on track performance.

## 3. PROGRESS IN TRACK SYSTEM MODEL DEVELOPMENT

### 3.1 Scope of Work

Figure 1 is a schematic diagram of the track system. It describes the main interactive processes which link the vehicle dynamic force inputs experienced by the track to the deterioration of track components and geometry. As shown, a vehicle of a given design, running over a track section of a given standard, at a given speed, will create a spectrum of track forces.

These forces are transmitted into the track, causing wear and fatigue of track components and deterioration of track geometry. The distribution of these forces depends on track design and the condition of the track components. Repair and replacement costs are incurred due to component wear and fatigue. Deterioration of track geometry increases track errors and leads to larger dynamic wheel loads as subsequent trains pass. This cycle continues until track components

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[2] "Rail Profile Grinding," S.T. Lamson, CIGGT Report 82-7, November 1982; "Rail Profile Grinding -- Phase II," S.T. Lamson, CIGGT Report No. 84-14, February 1985.

[3] "Assessment of Steel Railway Ties," M.L. Driscoll, S.T. Lamson, CIGGT Report No. 85-8, October 1985.

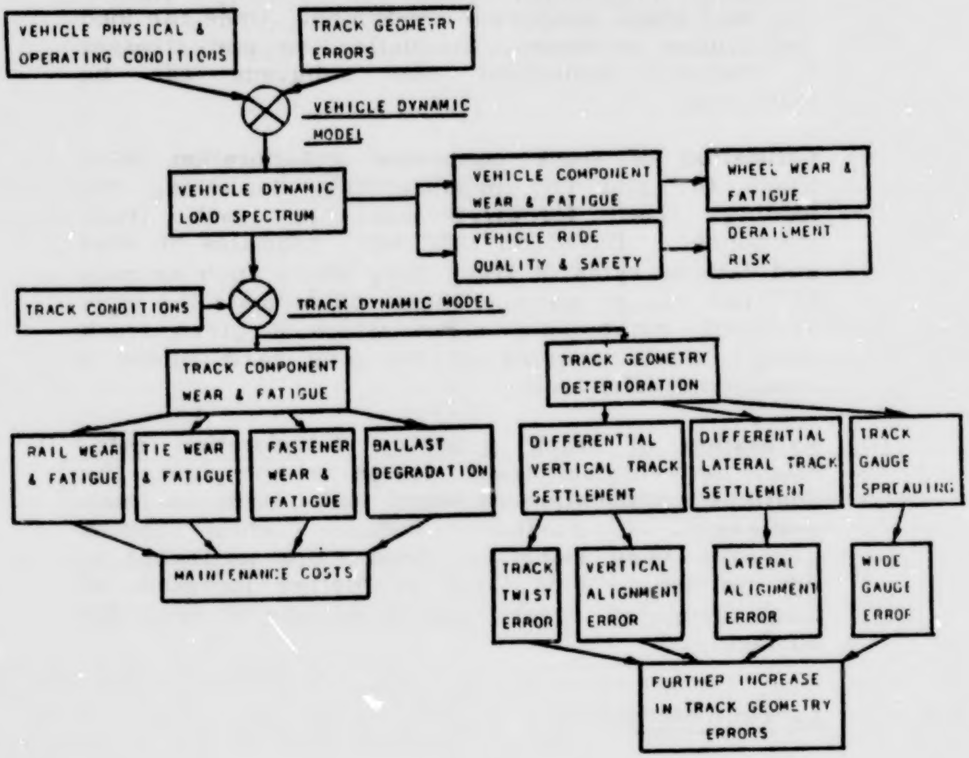
VEHICLE PHYSICAL & OPERATING CONDITIONS
TRACK GEOMETRY ERRORS
VEHICLE DYNAMIC MODEL
VEHICLE DYNAMIC LOAD SPECTRUM
VEHICLE COMPONENT WEAR & FATIGUE
WHEEL WEAR & FATIGUE
VEHICLE RIDE QUALITY & SAFETY
DERAILMENT RISK
TRACK CONDITIONS
TRACK DYNAMIC MODEL
TRACK COMPONENT WEAR & FATIGUE
TRACK GEOMETRY DETERIORATION
RAIL WEAR & FATIGUE
TIE WEAR & FATIGUE
FASTENER WEAR & FATIGUE
BALLAST DEGRADATION
DIFFERENTIAL VERTICAL TRACK SETTLEMENT
DIFFERENTIAL LATERAL TRACK SETTLEMENT
TRACK GAUGE SPREADING
MAINTENANCE COSTS
TRACK TWIST ERROR
VERTICAL ALIGNMENT ERROR
LATERAL ALIGNMENT ERROR
WIDE GAUGE ERROR
FURTHER INCREASE IN TRACK GEOMETRY ERRORS

Figure 1 Track system

and geometry are reconditioned. Thus, vehicle performance and track response are inter-related, and the track deterioration process is generally self-accelerating.

To understand and quantify the behaviour and interaction of such systems, the following work must be carried out:

(a) **Determination of track loading.** For each vehicle type in a traffic mix, the necessary track loading information is its dynamic wheel load spectrum. Of this, the minimum information is the steady-state level and dynamic variation of the wheel force in the vertical and lateral direction.

(b) **Determination of track response.** For any given set of dynamic wheel forces from given traffic, there is a corresponding set of forces on ties and ballast. This load distribution varies with track configuration and track component conditions. Once the load distribution is known, the deflections and stresses in ballast, subballast and subgrade can be estimated.

(c) **Estimation of track component deterioration rate.** Steps (a) and (b) produce data describing the loading (i.e. forces/stresses) on each track component. Based on this data, estimates of wear and fatigue rates of track components such as rails and ties can be made. These will indicate the level of track maintenance effort which a given track design would require in the long term under a specified traffic level.

(d) **Estimation of track geometry deterioration rate.** Since conventional track design is not rigid, the continued application of wheel loads leads to track settlement. Further, because wheel forces generally vary along the track, the settlement is not uniform. This leads to further increases in track geometry errors and eventually a need for surfacing.

## 3.2 Current Status

A track system model consisting of four modules has been developed. The modules are:

- the Vehicle Dynamic Model
- the Rail Life Model
- the Tie Life Model
- the Surfacing Model.

Figure 2 describes the structure of the model. The Vehicle Dynamic module produces the key components of the dynamic wheel load for each set of traffic/track conditions.

Outputs from this module are fed to the Rail, Tie and Surface modules to calculate track component and geometry degradation and maintenance cost.

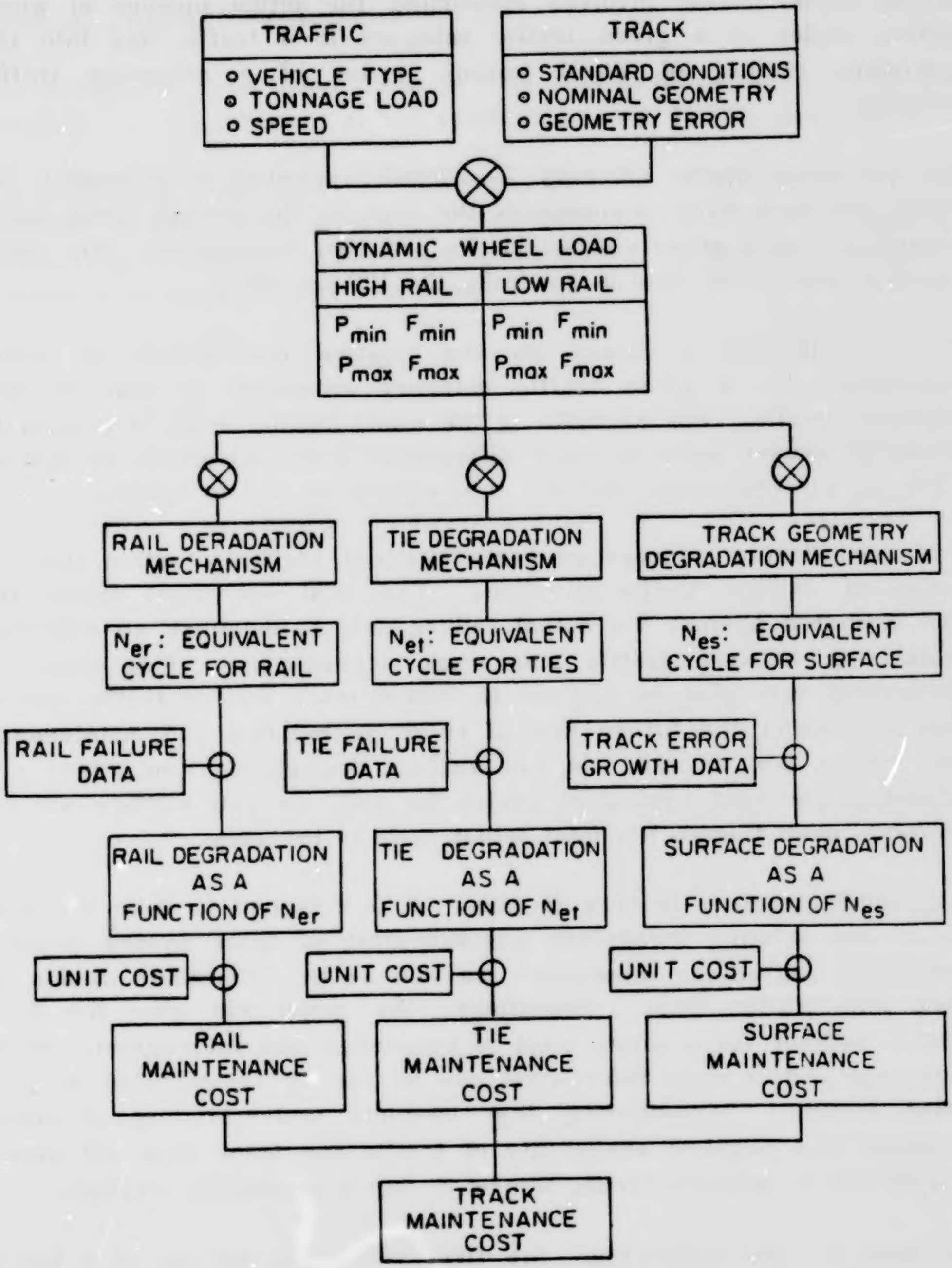
TRAFFIC
o VEHICLE TYPE
o TONNAGE LOAD
o SPEED
TRACK
o STANDARD CONDITIONS
o NOMINAL GEOMETRY
o GEOMETRY ERROR
DYNAMIC WHEEL LOAD
HIGH RAIL
LOW RAIL
$P_{min}$ $F_{min}$
$P_{max}$ $F_{max}$
$P_{min}$ $F_{min}$
$P_{max}$ $F_{max}$
RAIL DERADATION MECHANISM
TIE DEGRADATION MECHANISM
TRACK GEOMETRY DEGRADATION MECHANISM
$N_{er}$: EQUIVALENT CYCLE FOR RAIL
$N_{et}$: EQUIVALENT CYCLE FOR TIES
$N_{es}$: EQUIVALENT CYCLE FOR SURFACE
RAIL FAILURE DATA
TIE FAILURE DATA
TRACK ERROR GROWTH DATA
RAIL DEGRADATION AS A FUNCTION OF $N_{er}$
TIE DEGRADATION AS A FUNCTION OF $N_{et}$
SURFACE DEGRADATION AS A FUNCTION OF $N_{es}$
UNIT COST
UNIT COST
UNIT COST
RAIL MAINTENANCE COST
TIE MAINTENANCE COST
SURFACE MAINTENANCE COST
TRACK MAINTENANCE COST

**Figure 2** **Track System Maintenance Cost Model**

A key feature of the model structure is the normalization of the wheel loading cycle. This involves converting the actual number of wheel loading cycles of a given traffic category in a traffic mix into the equivalent number of wheel loading cycles of a reference traffic category.

The reference traffic category is normally selected to represent the traffic category which contributes the most to the overall track maintenance cost and whose characteristics are most understood. For North American main lines, this is generally the 100-ton car.

The normalization is based on the relative contribution to track degradation by a given traffic category compared to that by the reference traffic. For example, if the wheel loading cycle of a six-axle locomotive causes twice as much differential track settlement as that of a 100-ton car (reference traffic), it is equivalent to two cycles.

This normalization process converts a mixed traffic situation into an equivalent uniform traffic situation. The total equivalent cycles are then compared against the actual failure data to establish an empirical relationship between traffic and track degradation. This empirical relationship can later be applied to future track and/or traffic conditions to predict the future rate of track degradation and maintenance cost. Note that as rail, tie and surface degradation mechanisms are different, the total equivalent cycles for rail, tie and surface will be different, even though the total actual cycle is the same.

This model structure is very flexible. It is designed to make the best use of the existing incomplete understanding of track system performance and degradation processes, as well as the incomplete details of track and traffic data. Essentially, the model will give the best possible answer for a given level of knowledge and information. More knowledge and/or more information can be readily incorporated to give better results. Considering that complete understanding of track behaviour and complete availability of traffic and track data will never be achieved in absolute terms, this is in fact a reasonable strategy.

For ease of trial application, the first version is set up in a Lotus 1-2-3 worksheet format. The constraints of a worksheet format necessitate some simplifications, and hence reduced accuracy. However, in this format the model can be run on a microcomputer by an operator with no programming background.

Arrangements have been made to test this model against a real track maintenance environment at the subdivision level in the near future.

It should be noted that the individual modules of the model have been applied to analysis of some aspects of track maintenance on a number of operating railroads. These will continue to be upgraded as further research findings become available.

# REINFORCED EMBANKMENTS

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## ABSTRACT

The use of reinforcement, commonly consisting of geotextiles or geogrids, to stabilize embankments is discussed. There are three broad goups of applications; viz. fill slopes on good foundations, rehabilitation of natural slopes and the reinforcement of fill to compensate for weak foundations. Examples of each group are given and design methodologies noted. One unreinforced and two reinforced embankments near St. Albans Que., all instrumented, were constructed to failure. Data derived from this work are discussed.

# REINFORCED EMBANKMENTS

Reinforcement, commonly consisting of geotextiles or geogrids can be used to stabilize embankments in three groups of applications.

- Fill slopes on good foundations
- Rehabilitation of natural slopes
- Reinforcement of fill to compensate for weak foundations.

The first two groups involve problems of stability and deformation within the "placed" soils comprising the embankment. The first group includes the vertical or near vertical reinforced earth wall type applications. It also includes flatter slopes which are an efficient use of geotextiles and which do not require facing panels.

The second group encompasses the rehabilitation of natural slopes. In these applications, the reinforcement does not directly provide the stabilization, but rather permits the placing of a berm or drainage layer which stabilizes the slope.

The third group includes those examples in which reinforcement is provided in the fill in order to compensate for a weak foundation.

There are many examples quoted in the literature where reinforcement has been successfully used to improve the stability of embankments constructed on weak foundations.

Many of the case records have been tabulated by Milligan (1985). From these case records, it is apparent that reinforcement has generally been included in low embankments constructed on soft plastic clay foundations. Direct measurements of load in the reinforcement are scarce; interpretation usually requires some knowledge of the stress/strain properties and failure load of the geotextile, both of which are highly dependent on strain rate.

Limit equilibrium methods of analysis currently provide the most applicable design method, however, the errors and limitations of these methods, as understood from non-reinforced embankments, also apply to the reinforced case.

Alternatives to limit equilibrium methods include finite element analyses, but these suffer from the difficulty of defining accurate stress/strain parameters, both for the soil and the reinforcement, and they are generally unsuccessful in modelling and preciting the conditions at failure. Based on previous analytical studies, it could be postulated that the major effect of reinforcement inclusion in an embankment, is to cause a beneficial redistribution of stresses under the embankment with a consequential reduction in shear stress and displacement. The result is, of course, dependent on the relative rigidity of the reinforcement and the soil (Milligan and La Rochelle, 1984).

In order to measure the performance of reinforced embankments and their foundations, three instrumented embankments were constructed to failure at St. Alban, Quebec. One of the embankments was reinforced with two horizontal layers of Tensar SR-2 geogrid while another was reinforced with a sand filled geocell mattress, using the same quantity of reinforcement as used in the horizontal strips. To allow a direct comparison between unreinforced and reinforced embankments, the third embankment was unreinforced.

The work was carried out jointly by Golder Associates and Université Laval. It was sponsored by Supply and Services Canada, Transport Canada, National Research Council Canada and Energy Mines and Resources Canada.

The St. Alban site has a deposit of sensitive Champlain Clay under a thin surficial crust and is the same site on which an unreinforced embankment was constructed to failure by Université Laval in 1972. The performance of the two unreinforced embankments was used to calibrate the shear strength parameters and method of stability analysis. The same techniques were then adopted in order to assess the performance of the reinforced embankments. The calculations indicate that the horizontal layers of reinforcement allowed over 30 per cent increase in failure height, while the geocell reinforcement was only about half as effective in increasing the critical height.

Data will be presented showing the performance of the reinforcement, the embankments and the foundation subsoil. It is concluded that the main effect of the reinforcement is to maintain the integrity of the embankment as the foundation subsoil deforms. No beneficial effects of stress distribution or reduction in deformation could be identified under the reinforced embankments. The horizontal layers of reinforcement are easier to construct than the geocell mattress and they appear to offer the greatest improvement in failure height for the same quantity of reinforcement.

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# BALLAST AND GEOTEXTILE RESEARCH

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## ABSTRACT

Aggregate selection for ballast is discussed from the standpoints of how the aggregate weathers, how it resists load related degradation and how it contributes to track stability. Factors which influence the effectiveness of geotextiles installed to improve embankment stabilization and drainage are identified and discussed. The functions of subballast in improving railway track performance are reviewed and methods to ensure the desired improvement is achieved are described.

# BALLAST AND GEOTEXTILE RESEARCH

## INTRODUCTION

The introduction in the mid 1960's of the 100-ton car (which has a gross weight of 120 tonnes on four axles) not only led to a marked increase in track maintenance costs for the Canadian railways but also generated higher operating costs through extra delays to trains.

One response was to initiate research into track support. In 1970 the writer was provided with track support research funding by CN Rail, CP Rail, and the Research and Development Centre of Transport Canada through the Canadian Institute of Guided Ground Transport. As a result we now enjoy a much better understanding of the interaction of track forces and track support.

## AGGREGATE SELECTION FOR BALLAST

The initial research undertaken for the Canadian railways concentrated on the selection of aggregate for ballast. These areas relate to how the aggregate weathers, how it resists load related degradation and how it contributed to track stability.

The study of ballast weathering had two main facets. Firstly, the resistance of the aggregate to the crystallization or acidity of impurities dissolved in rainwater or from daily or seasonal fluctuations in temperature or other weathering processes. Secondly, the chemical degradation resulting from the action of rainwater on foreign source fines. For example, sulphur in coal produces acidity which would attack minerals such as calcite in limestones. The main engineering tests which identify with the first set of weathering processes are the Magnesium Sulphate test and the Absorption test. However, of much greater significance is a petrographic analysis since it gives a guidance to both processes. Petrographic analysis was strongly recommended for adoption by all railroads selecting new ballast sources.

The study of ballast load related degradation investigated the fracture of ballast particles and the surface wear of particle contact to particle contact. The main engineering tests identified as related to load related degradation were the Los Angeles Abrasion test, which gives a measure of the aggregate's toughness, and the Mill Abrasion test, a special test adapted at Queen's University to measure rock hardness and thus particle contact wear. The results of these two tests were combined in what has become known as the Aggregate Index or Abrasion Number. This value of Aggregate Index or Abrasion Number has been correlated by CP Rail to give a guide to aggregate life based on the mix of traffic using CP lines.

Track stability studies related to ballast focused on the aggregate's contribution to maintaining track line and level. The engineering tests related to an aggregate's ability to maintain track stability are the Bulk Specific Gravity of the aggregate and the particle's Shape and Fracture surfaces. Bulk Specific Gravity measures indirectly the weight of the ballast per cubic foot and heavier track is generally considered more stable than lightweight track. Particle Shape and Fracture Surfaces measure indirectly the ability of the particles to interlock and thus remain in a coherent mass when subject to high vibrations or dynamic forces.

Typical ballast test limit values, as specified by CP rail and in keeping with the results obtained by the writer's research findings are shown in Table 1.

## GEOTEXTILES

Although relatively new, the use of synthetic textiles or geotextiles has grown rapidly since their introduction to civil engineering by Mr. Robert J. Barrett in 1958 for a shore protection problem. Haliburton (1982), in a railway sponsored study, noted that geotextile use in railway applications should permit a further option for improving track support stabilization although little factual data was presented. Fortunately, many railways were, in the early 1980's, making rapid use of geotextiles from which factual data was obtainable. The writer was requested as part of the Canadian railways track research to undertake an investigation of the use of geotextiles in railway subgrade stabilization. This study quickly found that these new geotextiles over the short term provided technical improvements and lowered either construction costs or maintenance costs or both. Unfortunately these improvements were not always long-lasting and for long term applications a much greater discrimination between geotextile types and materials was found to be essential. For long-term applications not only are the geotextile's individual properties of importance but also the choice of the correct construction procedure and the matching of the geotextile's properties with the soils engineering properties essential.

It was found that the design of tracks on subgrades identified as likely to be unstable if ballasted without the use of a separation layer (i.e. subgrades containing 25% passing 74 micron sieve) will need to incorporate within the cross section both good drainage practice (see Figure 1) and a suitably graded granular subballast or a granular-geotextile combination to function as a separation layer. Such granular material should contain a small percentage (3 to 5%) of material passing the 74 micron sieve that is also non-plastic (Liquid Limit less than 25 and Plasticity Index less than 6 as per ASTM D1241).

Track that has been constructed with the deficiency of a suitable separation layer, or whose drainage is poor, or that is impacted at discontinuities of the rail such that segregation of fines from within the separation layer occurs, will need rehabilitation that should incorporate drainage improvement and possibly a heavy geotextile.

Attention was recommended to be directed to improving internal track drainage. This involves the sloping of interface layers or undercut surfaces towards drainage ditches or French drains. In particular the creation of Canal or Bathtub effects during rehabilitation should be avoided. Proper and adequate perpendicular drains to prevent water accumulating in the track structure or in French drains should be incorporated in rehabilitation work.

Recommended procedures for undercutting track without the use of geotextiles are illustrated in Figure 2. Rehabilitation with geotextiles are illustrated in Figures 3, 4, 5 and 6. The sequence for undercutting and installing geotextiles below turnouts was presented in the project report and illustrated in Figures 7, 8 and 9. Particularly stressed was the importance of locating the discharge sides of a geotextile below the level of the undercut bearing surface.

Since in situ performance of geotextiles were found to be dependent of the manufacturing process a 100 per cent "performance" specification was not considered presently acceptable. The recommended requirements for geotextiles included (1) Type; Needlepunched nonwoven with 80 penetrations per $cm^2$ or greater, (2) Fiber Size; Seven denier or less, (3) Fiber strength; Four grams per denier or greater, (4) Fiber polymer; Polyester preferred or Polypropylene, (5) Yarn length; 100 mm or greater, (6) Equivalent Opening Size; 74 microns or less, (7) In plane coefficient of permeability; 0.005 cm per sec or greater, (8) Elongation; Sixty per cent or more to ASTM D1682, (9) Colour; Must not cause "Snow Blindness", (10) Packaging; Must be weatherproofed and clearly identified at both ends stating manufacturer, width, length, type of geotextile, date of manufacture, (11) Wrapping; 8 mil black polyethyline or similar, (12) Abrasion Resistance; For 1050 $g/m^2$ geotextile must withstand 200 kPa on 102 mm burst sample after 5000 revolutions of H-18 stones each loaded with 1000 grams of rotary platform double head abraser (ASTM D-3884), (13) Width and length without seaming; To be specified by client, (14) Fiber bonding by resin treatment or similar; 5% to 20% low modulus acrylic resin or other suitable process that leaves geotextile pliable, (15) Mass; 1050 $g/m^2$ or greater for track rehabilitation without the use of capping sand.

## SUBBALLAST

Research undertaken by the writer identified, in addition to subballast acting to give sufficient depth of cover to the subgrade, the following functions and requiremets

1. to act as a (cheap) ballast material having an ability to spread the load from the vehicle's axles and wheels to the earthen foundation beneath the track structure (generally met by specifying some minimum strength or Los Angeles Abrasion to the coarse aggregate portion),

2. to prevent or at least minimize surface water from penetrating the subgrade. As such it must be (partially) impermeable in relation to the ballast (generally met by specifying a small percentage of particles of 74 micron size),

3. to permit an easy exit of water retained within the voids of the subgrade soil when subjected to compression from vehicle loading. As such subballast must be considerably more permeable than the subgrade. Both are considerably less permeable than the ballast (generally met by limiting the Liquid Limit and Plasticity Index of the finer aggregate portion and by the ratio of the particle sizes at the fifteen percent passing limits of the subballast and the subgrade), and

4. to filter and separate the subgrade fines from entering the ballast and thus from complete penetration of the subballast's own internal voids (generally met from the ratio of some particle size representing the finer portion of the subballast to some particle size representing the coarser fraction of the subgrade soil. A similar ratio is required to prevent the subballast's own particles entering the ballast),

5. in cold climates the percentage of material passing the 74 micron sieve must be limited to prevent frost susceptibility of the subballast (generally 5% for broadly graded material and 10% for material void of gravel sized material).

A number of alternative methods of meeting the above requirements are possible. The American Railway Engineering Association's (AREA) Manual for Railway Engineering (Chapter 1, Section 2.10) suggests the use of a broadly graded granular subballast. This is one solution. Another solution is to use a capping sand to filter the subgrade fines. This capping sand would then be covered by a geotextiles or an open graded fine gravel. Ballast would then be placed directly on the open fine gravel or the geotextile. The geotextile could be covered with an open graded granular covering of fine gravel size particles as a protective layer against ballast penetration. A third alternative would be to use a broadly graded sand that would include both some fine gravel sizes and some fines (i.e. minus 74 microns). These gradings, along with notes related to their use, are given in Table 2 and are shown as typical grading curves in Figure 10. Figure 10 also shows CN's (1985) ballast grading and CP's (1985) maximum ballast grading. In all cases their surfaces should be sloped.

It must be stressed that subballast material is relatively impermeable in relation to the ballast and should be laid so that any subballast interface surface water can drain by gravity to the side ditches. Where this cannot occur ponding and pumping may result and geotextiles may be required on subballast surfaces situated below high impact areas such as transition zones (i.e. bridge approaches) and below discontinuities such as occurs at turnout and rail joints. Such geotextiles must have their side edges located at the lowest elevation so water discharges away from the track bearing area of track.

**ACKNOWLEDGEMENT**

Much of the work reported herein was done under Canadian Institute of Guided Ground Transport contracts funded by CN Rail, CP Rail, and TDC of Transport Canada. Acknowledged is the kindness shown by Messrs. W.A. Swartz, M.L. Heide and A.H. Blair of Conrail to observe geotextile performance at Conrail's test sites, and the co-operation given by numerous CN Rail personnel, in particular Messrs. A.W. Worth, R. Gillespie and B. Beaton, to allow numerous excavations of geotextiles as directed by the writer. Also acknowledged is co-operation of numerous former students who worked with the Author, particularly Mr. W.J. Purdy, and the advice received from Mr. D.F. Vandine and Mr. B. Gerry both formerly of Queen's University.

**TABLE 1 SUMMARY - CP RAIL BALLAST SPECIFICATION LIMITS**

| BALLAST STANDARDS | MAINLINE | | | BRANCH | |
|---|---|---|---|---|---|
| | CWR | JOINT | 2nd | MAJOR | MINOR |
| **STABILITY** | | | | | |
| B.S.G. ≮ | 2.60 | 2.60 | 2.60 | 2.60 | 2.60 |
| CRUSHED P. | | | | | |
| AREA 3 ≮ | 100 | - | - | - | - |
| AREA 4 ≮ | 90 | 85 | 75 | 65 | 65 |
| AREA 5 ≮ | N/A | 70 | 60 | 60 | 60 |
| **WEATHERING** | | | | | |
| $MgSO_4$ ≯ | 1.0 | 1.5 | 3.0 | 3.0 | 3.0 |
| ABSORPTION ≯ | 0.50 | 0.75 | 1.0 | 1.0 | 1.0 |
| **ABRASION** | | | | | |
| L.A.A. ≯ | 45 | 45 | 45 | 45 | 45 |
| M.A. ≯ | 9 | 9 | 9 | 9 | 9 |
| LAA + 5 MA ≯ | 65 | 65 | 65 | 65 | 65 |

LIFE ≮ 20 YEARS PREFERABLY > 30 YEARS
WHERE LIMITS MET, PETROLOGIC ANALYSIS MAY OVERRIDE

## TABLE 2 SUBBALLAST GRADING LIMITS

| SIEVE SIZE | CAPPING SAND [1] | FILTER SAND [2] | OPEN GRADED SUBBALLAST [3] | BROADLY GRADED SUBBALLAST |
|---|---|---|---|---|
| 1" |  | 100 | 100 | 100 |
| 1/2" |  |  | 51-100 | 51-100 |
| 3/8" |  | 80-100 | 30-80 | 48-80 |
| No 4 | 100 | 65-100 | 0-15 | 40-65 |
| No 8 |  | 55-85 | 0-3 |  |
| No 16 | 70-100 | 45-70 |  | 25-45 |
| No 50 | 25-70 | 25-45 |  | 10-25 |
| No 100 | 14-40 | 14-30 |  | 5-14 |
| No 200 | 5-15 | 5-15 |  | 3-5 |

1 CAPPING SAND SHALL BE COVERED BY 280 $g/m^2$ GEOTEXTILE

2 FILTER SAND SHOULD, PREFERABLY, BE COVERED BY OPEN GRADED SUBBALLAST OR 280 $g/m^2$ GEOTEXTILE ON HEAVY TONNAGE LINES

3 OPEN GRADED SUBBALLAST TO BE USED ONLY ON FILTER SAND OR ON GEOTEXTILE

BALLAST SHALL NOT BE PLACED DIRECTLY ON CAPPING SAND

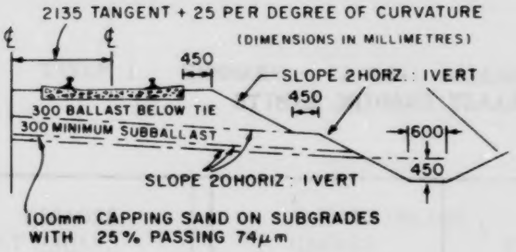

2135 TANGENT + 25 PER DEGREE OF CURVATURE
(DIMENSIONS IN MILLIMETRES)
℄
℄
450
SLOPE 2HORZ. : 1VERT
450
300 BALLAST BELOW TIE
300 MINIMUM SUBBALLAST
600
450
SLOPE 20HORIZ : 1VERT
100mm CAPPING SAND ON SUBGRADES WITH 25% PASSING 74μm

**Figure 1.** Typical Track Cross Section for New Double Track Construction.

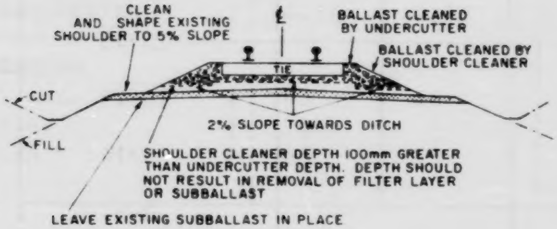

CLEAN AND SHAPE EXISTING SHOULDER TO 5% SLOPE
℄
BALLAST CLEANED BY UNDERCUTTER
BALLAST CLEANED BY SHOULDER CLEANER
TIE
CUT
FILL
2% SLOPE TOWARDS DITCH
SHOULDER CLEANER DEPTH 100mm GREATER THAN UNDERCUTTER DEPTH. DEPTH SHOULD NOT RESULT IN REMOVAL OF FILTER LAYER OR SUBBALLAST
LEAVE EXISTING SUBBALLAST IN PLACE

**Figure 2.** Recommended Undercutting and Shoulder Ballast Rehabilitation.

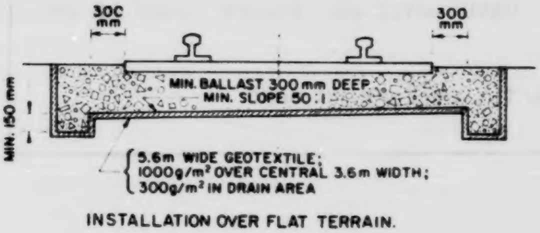

300 mm
300 mm
MIN. BALLAST 300 mm DEEP
MIN. SLOPE 50:1
MIN. 150 mm
5.6m WIDE GEOTEXTILE; 1000g/m² OVER CENTRAL 3.6m WIDTH; 300g/m² IN DRAIN AREA
INSTALLATION OVER FLAT TERRAIN.

**Figure 3.** Recommended Undercutting with French Drains over Flat Terrain.

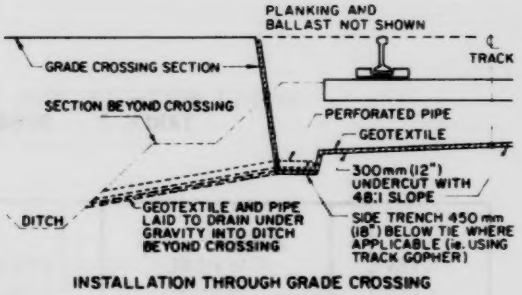

PLANKING AND BALLAST NOT SHOWN
℄ TRACK
GRADE CROSSING SECTION
SECTION BEYOND CROSSING
PERFORATED PIPE
GEOTEXTILE
300mm (12") UNDERCUT WITH 48:1 SLOPE
DITCH
GEOTEXTILE AND PIPE LAID TO DRAIN UNDER GRAVITY INTO DITCH BEYOND CROSSING
SIDE TRENCH 450 mm (18") BELOW TIE WHERE APPLICABLE (ie. USING TRACK GOPHER)
INSTALLATION THROUGH GRADE CROSSING

**Figure 4.** Typical Grade Crossing Rehabilitation with Geotextile.

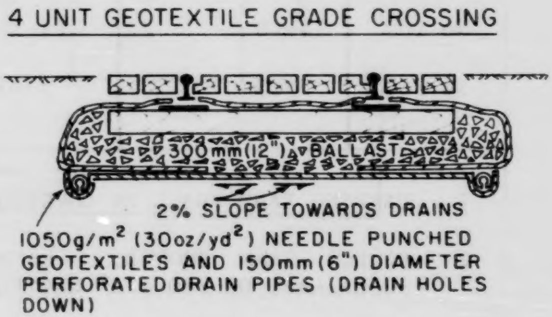

4 UNIT GEOTEXTILE GRADE CROSSING
300mm (12") BALLAST
2% SLOPE TOWARDS DRAINS
1050g/m² (30oz/yd²) NEEDLE PUNCHED GEOTEXTILES AND 150mm (6") DIAMETER PERFORATED DRAIN PIPES (DRAIN HOLES DOWN)

**Figure 5.** Recommended Grade Crossing Rehabilitation with Encapsulating Geotextile to Minimize Fouling by Salting and Sanding.

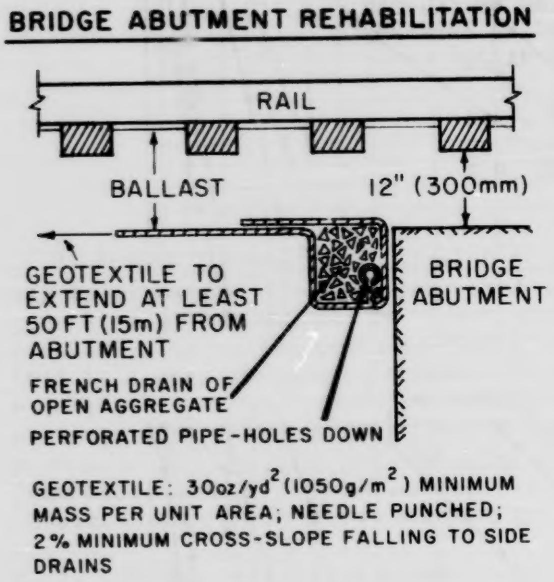

BRIDGE ABUTMENT REHABILITATION
RAIL
BALLAST
12" (300mm)
GEOTEXTILE TO EXTEND AT LEAST 50 FT (15m) FROM ABUTMENT
BRIDGE ABUTMENT
FRENCH DRAIN OF OPEN AGGREGATE
PERFORATED PIPE-HOLES DOWN
GEOTEXTILE: 30oz/yd² (1050g/m²) MINIMUM MASS PER UNIT AREA; NEEDLE PUNCHED; 2% MINIMUM CROSS-SLOPE FALLING TO SIDE DRAINS

**Figure 6.** Typical Method of Rehabilitating Bridge Abutments Using Geotextiles.

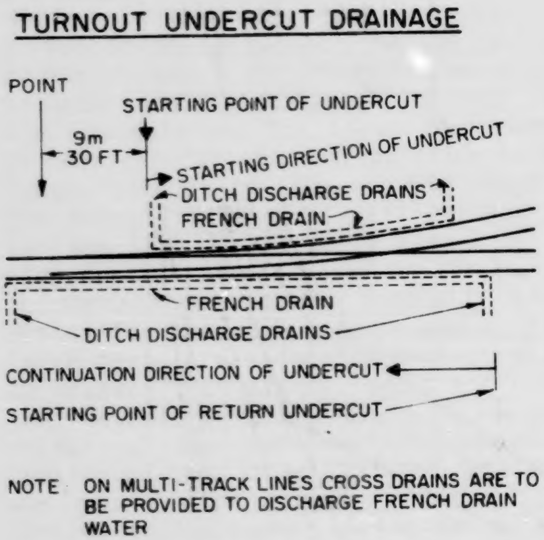

TURNOUT UNDERCUT DRAINAGE
POINT
STARTING POINT OF UNDERCUT
9m
30 FT
STARTING DIRECTION OF UNDERCUT
DITCH DISCHARGE DRAINS
FRENCH DRAIN
FRENCH DRAIN
DITCH DISCHARGE DRAINS
CONTINUATION DIRECTION OF UNDERCUT
STARTING POINT OF RETURN UNDERCUT
NOTE ON MULTI-TRACK LINES CROSS DRAINS ARE TO BE PROVIDED TO DISCHARGE FRENCH DRAIN WATER

**Figure 7.** Depth of Geotextile - Abrasion Assessment for Recovered Track Geotextiles.

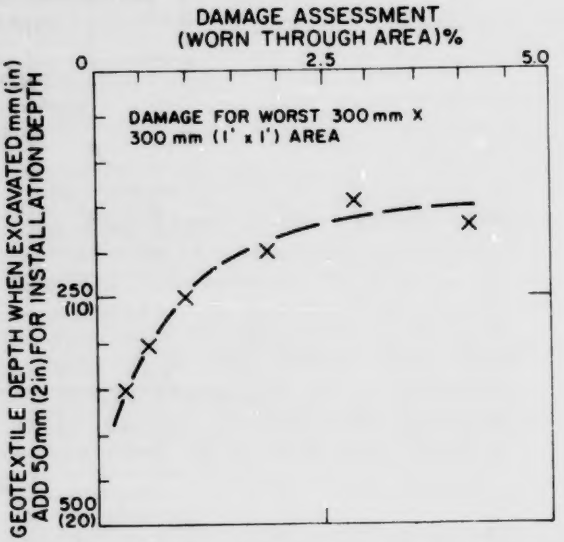


**Figure 8.** Plans of Sites Excavated on CN's Atlantic Region During June 1985.

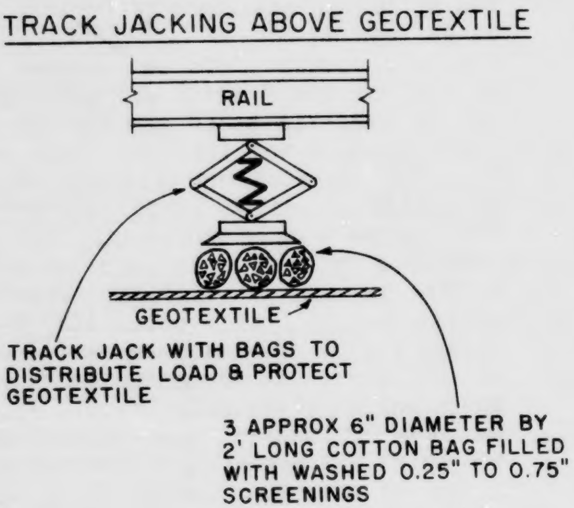

TRACK JACKING ABOVE GEOTEXTILE
RAIL
GEOTEXTILE
TRACK JACK WITH BAGS TO DISTRIBUTE LOAD & PROTECT GEOTEXTILE
3 APPROX 6" DIAMETER BY 2' LONG COTTON BAG FILLED WITH WASHED 0.25" TO 0.75" SCREENINGS

**Figure 9.** Method of Protecting Geotextiles from High Imprint Pressure of Rail Jack Bases.

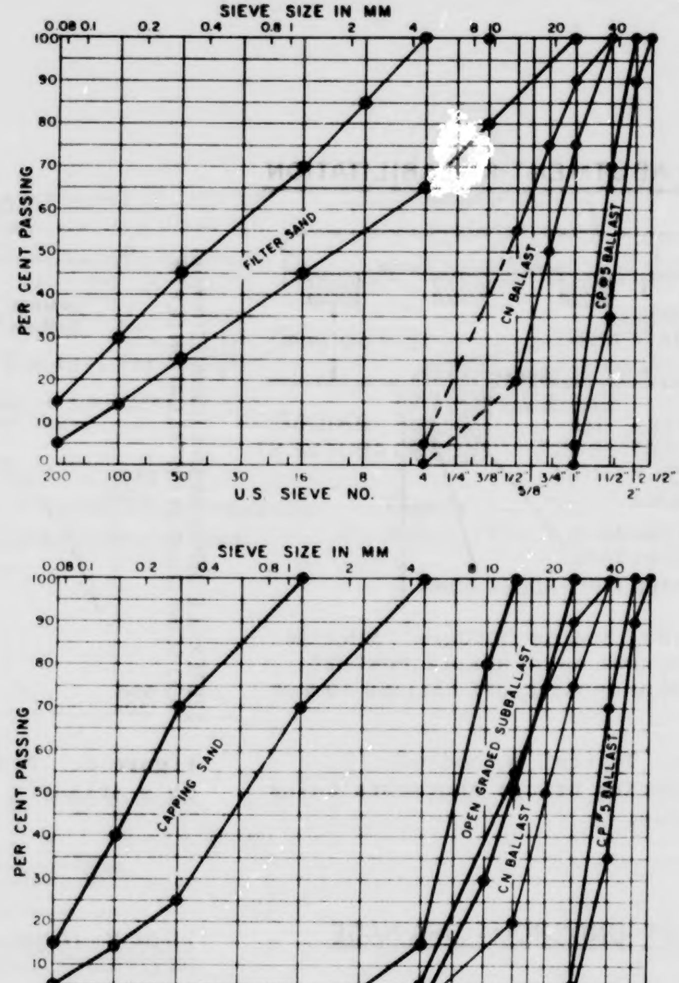


**Figure 10.** Grading Curves of Suggested Subballast and Its Alternative Options.

# DISCUSSION ON PRESENTATION BY MEMBERS OF TRACK STRUCTURE RESEARCH PANEL

S. T. LAMSON
J. R. BUSBRIDGE
G.P. RAYMOND

F. B. BLADER (Consultant): I wish to address a question to Mr. Lamson. The way he presented his work suggested to me that in his assessment of forces generated by models of the track structure and the vehicle structure, he eventually generates profiles for grinding purposes. I would suggest that that is a very dangerous procedure to adopt for identifying profiles because essentially, actual profiles result not only from the forces and from whatever wear patterns they create, but the forces themselves are completely a result of the profiles as they currently exist, so you have to have feed-back, and a continuous loop in order to come up with a satisfactory result. Would you care to comment on that?

S. T. LAMSON: The first point is that the rail profile that eventually was tested on CP track was not just the result of computer simulation of truck curving. The computer simulation of truck curving was used to identify which feature of the wheel/rail profile interaction can be changed to affect the curving force on the truck. That gives one aspect and that aspect is simply the influence of the rolling radius difference between the left rail and right rail (high rail and low rail in a curve). That rolling radius difference has been seen and has been generally confirmed by different works, to be influential on the curving force in shallow and perhaps up to medium curves. But that is one aspect only. The other aspect that was brought into the design of the rail profile was the false flange contact on the low rail and for that, the remedial action was based strictly on the geometrical contact configuration between wheel and rail for a given track gauge. The third item was the gauge corner shelling on the high rail. On the basis of the wheel/rail contact interaction based on the geometry, we can see that at the gauge corner of the rail there are high creepages and high contact stress based on the curvature of the rail and wheel contours. So these three factors basically are brought together to come up with a design for the rail profile and we tested that twice. In 1982, we set up three test curves and the test curves were instrumented with strain gauges to measure the lateral forces and also with measurements of corrugation on the low rail and observation of the surface cracks, especially on the gauge corner of the high rail. Two of the curves were ground to what we considered then to be the candidate for an optimum profile and the third one was ground with a heavy grinding of the gauge corner and also to put a contact in the centre of the rail. We found that the heavy grinding of the gauge corner created an increase in the lateral force in one curve. In the other two curves, there were mixed results depending on different runs of the train; that is, over balance speed or below balance speed. Generally, there was either no effect or some small reduction in the force. But that is only lateral force, which will have some influence on the gauge face wear.

In terms of corrugation, we found that the grinding we used was quite effective in reducing corrugation. We have observations of those curves for up to 50 MGT. In terms of gauge corner shelling, there appears to be some improvement as well. But the test was small, only three curves, so we decided in 1984 to do it again, this time with 15 test curves. That was enough to look at three small variations of the profiles. In one case on the gauge corner, we looked at the three choices: to grind the gauge corner as much as we used to do for the preferred design; in the second case to grind a lot more and in the third case to grind a lot less. We found that grinding a lot more is actually more beneficial than the other cases. The preferred grinding that we used for the gauge corner was not as good, but it is not too bad. On the corrugation, the results clearly confirmed that that kind of grinding actually reduced the corrugation growth.

In terms of gauge face wear, we found that the small variations that we tried did not really have any great effect on the gauge face wear of the high rail.

So we did not just do computer simulations. We did tests very carefully and the important thing is that the work at CP, started in 1982, was preceded by the work in Australia which was done in 1979-80. The Australians have used the technique until now and they have seen the actual benefit in terms of cost of their rail replacement. Finally, the safety aspect is fine. There is no adverse effect on safety.

F. B. BLADER: You did not quite answer the question. The question was: How do you account for the "closed-loop" nature of the process? Certainly if you grind off the gauge corner, you are not going to get any contact there and you are not going to generate any spalling. But what effect does that have on the ultimate wear process that goes on with the wheel and therefore the consequent wear process that goes on with the rail?

S. T. LAMSON: It is true that after some time, there will be a change in the average wheel contour of the wheel population. In Australia, they found that with profile grinding, the primary reason for wheel changeout was changing from flange wear to tread wear. but the change is quite small because the wear effect in curves is countered by the wear effect in tangent track. The lateral motion of the wheelset in tangent track tends to straighten out the tread wear; you know, where it is being curved by confining the contact to a more restricted zone, it tends to hollow the tread. So the tangent wear tends to balance it out. Right now, the grinding technique that we introduced, based on the test results, improves the condition of rail, but it is not the final word. It can only be seen as the immediate answer. More investment in the track and in track maintenance is needed to get a better solution.

I can cite a few things: the use of radial trucks, better wheel maintenance to eliminate false flanges, better maintenance of track gauge.

W. B. F. MACKAY (Queen's University): I have a question to Mr. Lamson. Rail grinding bothers me from a metallurgical point of view. You have heard me on this before, I think. I was just wondering if in the literature, there is anything you can allay my fears with. I am not talking about laboratory grinding, but in the field. To me, when I look at that, it is abusive grinding in the worst form. I have not had any experience myself with rail grinding but I have been in on enough failure analyses on ordinary grinding and machine parts and tools, that when I look at rail grinding out in the field, I just shudder. I have been trying to convince CP to cut out a section of rail and a few smaller parts and section it up a bit for me to take a look at it. I would like to see the microstructure of a badly corrugated rail; one that has been heavily ground in the field.

I still think with regard to grinding, that power, speeds, feed, rail travel, lack of cooling, the nature of the wheel, the grip size, the hardness, the rest of it, all have a bearing. I think you are abusively grinding the rail. Aside from taking out some of the cracks, I think you are just putting in a martensitic layer there and you are just asking for more trouble.

S. T. LAMSON: I have asked the railway grinding suppliers a few times. There was no answer; they assured me that there was no problem. Maybe Joe has some more information.

K. KALOUSEK: I share your impression. Seeing the rail being ground, I was also horrified and therefore I came up with this new theory of gentle grinding of the rail. From the metallurgical point of view, it makes a lot of sense if we grind less, remove just the very top and leave the work-hardened layer of the material which is still very strong and has the greatest strength, rather than remove it to almost the non work-hardened layer, which then almost fails, again generating a lot of cracks in the microstructure. All those things led us to the development of this new gentle grinding but it will have to be done more often and we have to do a lot of work to persuade the railways that there is money in it.

One more comment on this. A cooperative research program has been laid out between CIGGT, S. Lamson, myself, British Columbia Railway and CP Rail and in that project we will be taking a lot of plugs out of the track, both in preventive grinding tests and corrective grinding tests and if you want to help sectioning and polishing you are most welcome.

R. W. SMITH (Queen's University): Mr. Busbridge, I don't know anything about soil mechanics but I gather from your talk that you associated the failure of the reinforced embankment with the localized strain of the curve at the bottom. Is this right? You reinforced the embankment and then it failed. The reinforcing did not provide as much strengthening as you anticipated and you associated the failure with the localized strain which was 2% at the base of it rather than occurring gradually throughout the whole lot. Am I confused?

J. R. BUSBRIDGE: I was only giving the strain in one particular location being measured. That was where the load was building up to its maximum as well. Where the load was developing to its maximum extent was under the centre of the embankment and at that point I was commenting on what the strain in the reinforcement was. It was 2%, while the loading in the reinforcement was fairly small. The reason I am so interested in the strain is because of the creep characteristics of these materials which are being used to reinforce embankments. There is very little detail on the strains that actually develop at the base of embankments. This is one of the things we were concerned with establishing. The conclusion is that with this particular type of soil, which is quite treacherous, even at very low factors of safety, which is quite common in embankment design, the strain in the reinforcement is quite small, in the order of 2%. Does that answer your question?

R. W. SMITH: Yes.

## 2.6 Technical Session #3 - Freight Cars

### Session Chairman

Mr. R.W. Radford
Chief Mechanical & Electrical Engineer
CN Rail
Montreal, Que.

# TRAIN DYNAMICS SIMULATION

M.H.Kelley
Project Engineer
DSL Dynamic Sciences Limited
Montreal, Que.

## ABSTRACT

This presentation describes the capabilities and applications of a tool that will provide railway and other organizations with a real-time research and simulation capability for longitudinal train action and control. This tool has been packaged in the form of a real-time train simulation software program. The simulation program provides the ability for the operator to determine dynamic longitudinal forces at couplers and the longitudinal acceleration of cars within the train. It models air brakes, locomotive systems, and effects due to rolling and curve resistances and grade. It also provides for non-real-time operation (slower than real-time) which allows for more detailed generation of results. The program has been configured in a form which allows for a broad range of flexibility, including user interaction using friendly keys, batch or repeatable inputs, initiation of undesired conditions and malfunctions, and the ability to choose alternate track conditions during the run. The software program is in its testing phase and, in the near future, will be installed on NRC facilities so special research studies may be conducted.

# 1. INTRODUCTION

## 1.1 Background

The modern North American railroads are responding to a continued pressure to keep their operating costs under control, while facing high costs for both fuel and for the financing of new capital equipment. Changes in equipment design and operational practices characterize their response.

On the equipment design side, major design efforts are being directed to reduce tare weight of vehicles and to reduce aerodynamic drag and rolling resistance. Car designs of many different types are undergoing field test. Train sets of special equipment, including semi-permanently coupled rail cars are in revenue service. Changes such as these can eliminate conventional coupler mechanism and draft gear.

Canadian railroads must be in a position to evaluate these changes in equipment design in relationship to their own specific operating requirements. The Canadian rail industry must also be able to generate sound technical data, to support the development of new designs which will be best suited for Canadian operation.

On the operational side, changes to cut fuel costs are being implemented to the extent current knowledge allows. Efforts are made to dispatch trains and control their locations through signalling so that stops are avoided when possible and uniform running speeds are maintained. Emphasis is put on reduced use of the train air brakes while locomotives are in traction, and also on the increased use of dynamic braking.

Variations in train handling may represent new operating conditions which result in generation of high in-train force levels. In other cases, operating crews, uncertain of the effect train handling variations will have on their safety, stay with handling policies which are not economical. A rigorous analytical study of such operation can lead to handling policies which are economical and safe.

## 1.2 Objectives

As a result, TDC funded in 1983, the development of a train simulation program with DSL, expanding on DSL's current full train simulation capabilities. The objectives of this program were:

- To provide railways and other organizations with a real-time research and simulation capability for longitudinal train action and control.
- To develop a real-time digital simulation program for longitudinal train dynamics and control which provides the ability of the operator to determine dynamic longitudinal forces at couplers and the longitudinal acceleration of cars within the train.
- To set up the model on NRC facilities and to demonstrate its capabilities to potential users.

## 2. THE WORK

### 2.1 Work To Date

The following milestones have been achived to present:

- completion of the model for longitudinal train action and initial testing at NRC facilities;
- work was placed on hold while another simulator contract proceeded, the results of which have been applied to this program;
- completion of software development; and
- integration of the program in real-time incorporating a slower than real-time feature on DSL's MicroVAX II computer.

### 2.2 Remaining Work

A number of tasks still remain to be completed as listed below:

- Final testing at DSL facilities.
- Installation of NRC Mechanical Engineering's VAX 11/780.
- Final documentation and case studies.

## 3. CAPABILITIES

The best method to understand the simulation program is to discuss its capabilities. Listed are some of the major capabilities along with references to some of the simulation's generated displays and output data:

- Simulation can operate in either real-time or slower than real-time. The slower than real-time operation allows the user to investigate further dynamics responses by slowing down the simulation whereas real-time mode allows the user to interact with the simulation as in a real locomotive.

- Determine longitudinal coupler forces at each coupler pair. Figure 1 is an off-line plot of coupler forces versus time for specific coupler pairs using simulation generated data.

- Runs on a predefined (by user) track section. Figure 2 is a sample of track as displayed on the profile display. Curvature, track plan and gradient information are entered into the simulation at initialization and updated as required during the run.

- Accepts batch input which facilitates easy and repeatable testing. Inputs, such as altering train conditions and other events, are entered prior to commencement of a simulation session. These inputs are activated by time and position queues. The user can still interact with the simulation during run time when using batch input.

- Vehicle data and consist information are stored in library form and are referenced through the Run Specification Form at the beginning of the run. Figure 3 is a sample of the Run Specification Form. As shown in this figure, the user is given the option to choose what train consist and route desired for the simulation. The form also allows the user to establish some operating parameters. Figure 4 is a sample of the train consist chosen through the Mission Specification Form. This figure is a copy of the Consist Summary as displayed to the user at the beginning of each run following the completion of the Mission Specification Form.

- Use of various displays in the initiation and running of the simulation. This is a definite advantage over TOS when simulating a particular dynamic operating problem. Figure 5 is a sample of the trip log that is displayed to the user during the simulation run. It contains almost all the basic information required to understand what may be happening during the run. A printed version of the log is generated at the end of the simulation.

- User manipulation of control stand features through friendly (programmable) keys on the computer terminal. As shown in Figure 6, the bottom of the screen is reserved for interactive commands. The boxes shown represent function keys on the keyboard directly below the display. When they appear on the screen, the user activates the appropriate key to perform the stated function.

- Generation of special events and malfunctions such as break-in-two, hose breakage, kicker/dynamiter, loss of adhesion, hot engine, and many others. Figure 7 illustrates some of the options available to the user.

## 4. APPLICATIONS

The Dynamic Train Simulation Program tries to meet the needs of railway and industry, as described in Section 1.1, on at least the following fronts:

- Fuel Economy
- Train Handling
- Inter-Vehicle Dynamics
- Ergonomic Research
- Accident Investigation

For fuel economy, simulations can be run over the same stretch of track trying various operating methods to determine the most fuel efficient approach.

For train handling, simulations can be performed looking at the various ways of dealing with problems train consists generate high in-train longitudinal forces.

For inter-vehicle dynamics, the user can manipulate vehicle and operating parameters to reduce inter-vehicle dynamics and increase fuel efficiency.

For ergonomic research, the simulator provides an excellent tool in understanding some of the human/ machine problems related to air brakes and other systems.

As an accident investigation tool, the simulation program can repeat given conditions leading up to an accident to determine cause. The investigator will be able to interact with the simulation to determine if other actions would prevent recurrance.

## 5. FULFILLMENT OF OBJECTIVES

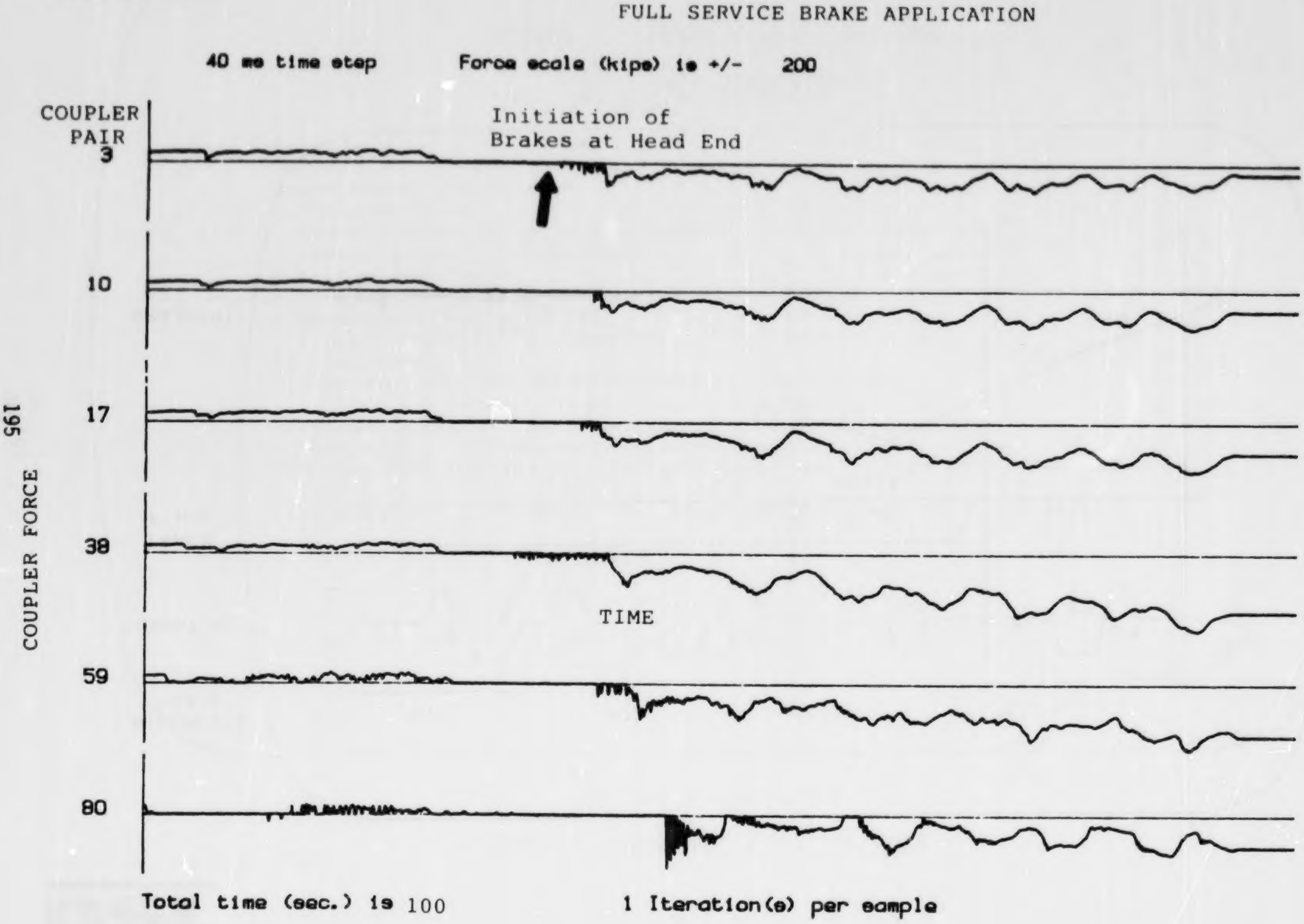
All objectives are being met in full.

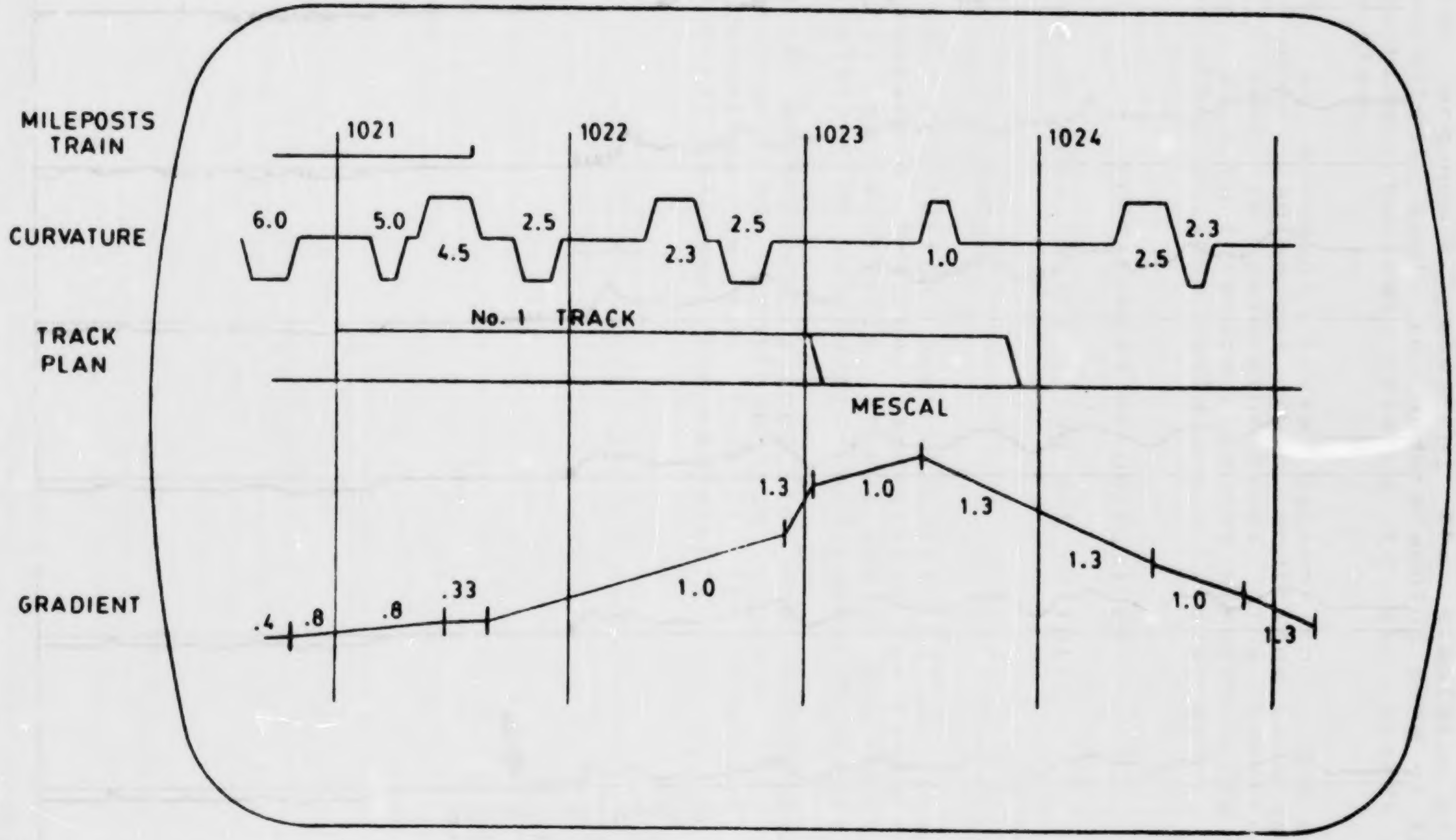
## 6. FUTURE

Upon completion and installation of the Dynamic Simulation Program, facilities for research studies will be available at NRC and at DSL (Montreal) for exploitation by industry and research groups.

With experience gained in the development of this program, DSL continues to enhance its simulator technology on two fronts: for training, and with special features, for research.

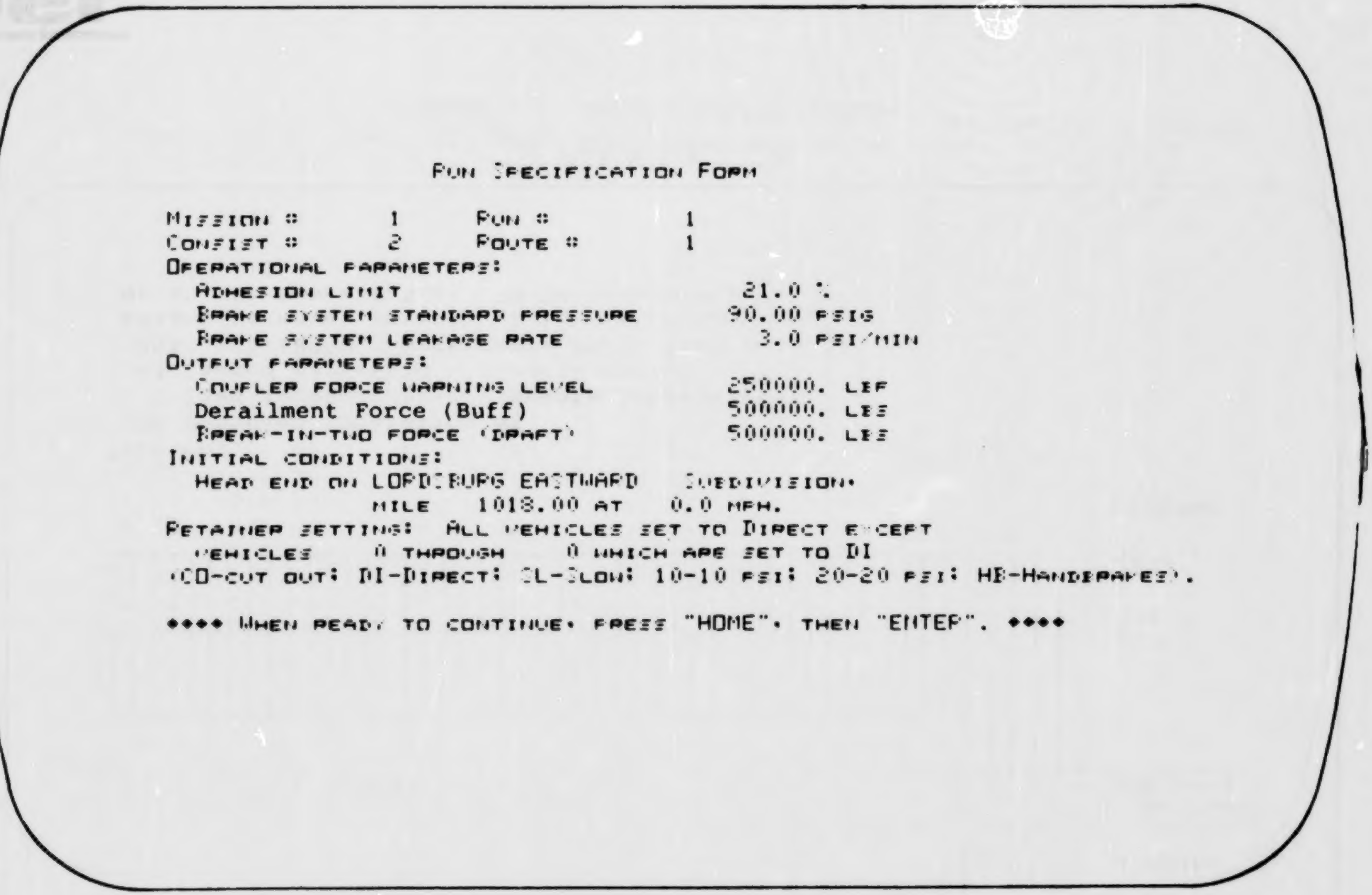
FIGURE 1 - PLOT OF COUPLER FORCE VERSUS TIME




MILEPOSTS
TRAIN
CURVATURE
TRACK
PLAN
GRADIENT
1021
1022
1023
1024
6.0
5.0
4.5
2.5
2.3
2.5
1.0
2.5
2.3
No. 1 TRACK
MESCAL
.4
.8
.8
.33
1.0
1.3
1.0
1.3
1.3
1.0
1.3

DSL TRAIN SIMULATOR

FIGURE 2 - TRACK PROFILE DISPLAY



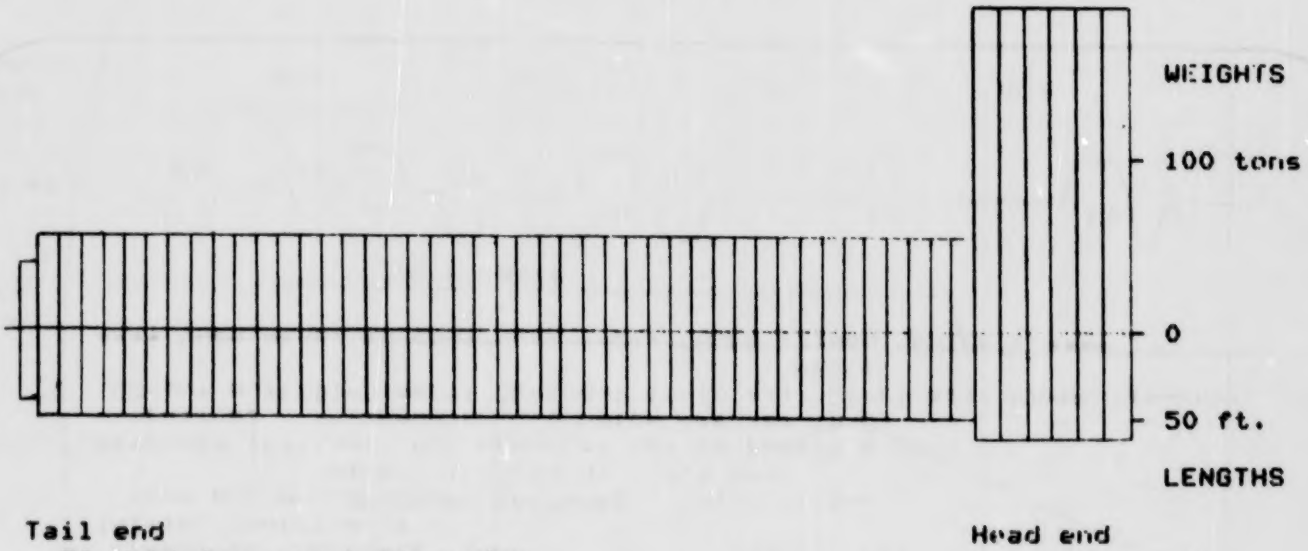
```
                    Run Specification Form

Mission #      1      Run #          1
Consist #      2      Route #        1
Operational parameters:
  Adhesion limit                           21.0 %
  Brake system standard pressure          90.00 psig
  Brake system leakage rate                 3.0 psi/min
Output parameters:
  Coupler force warning level            250000. lbf
  Derailment Force (Buff)                500000. lbs
  Break-in-two force (draft)             500000. lbs
Initial conditions:
  Head end on LORDSBURG EASTWARD   Subdivision.
              mile   1018.00 at    0.0 mph.
Retainer settings:  All vehicles set to Direct except
  vehicles    0 through     0 which are set to DI
(CO-cut out: DI-Direct: SL-Slow: 10-10 psi: 20-20 psi: HB-Handbrakes).

**** When ready to continue, press "HOME", then "ENTER". ****
```

DSL TRAIN SIMULATOR

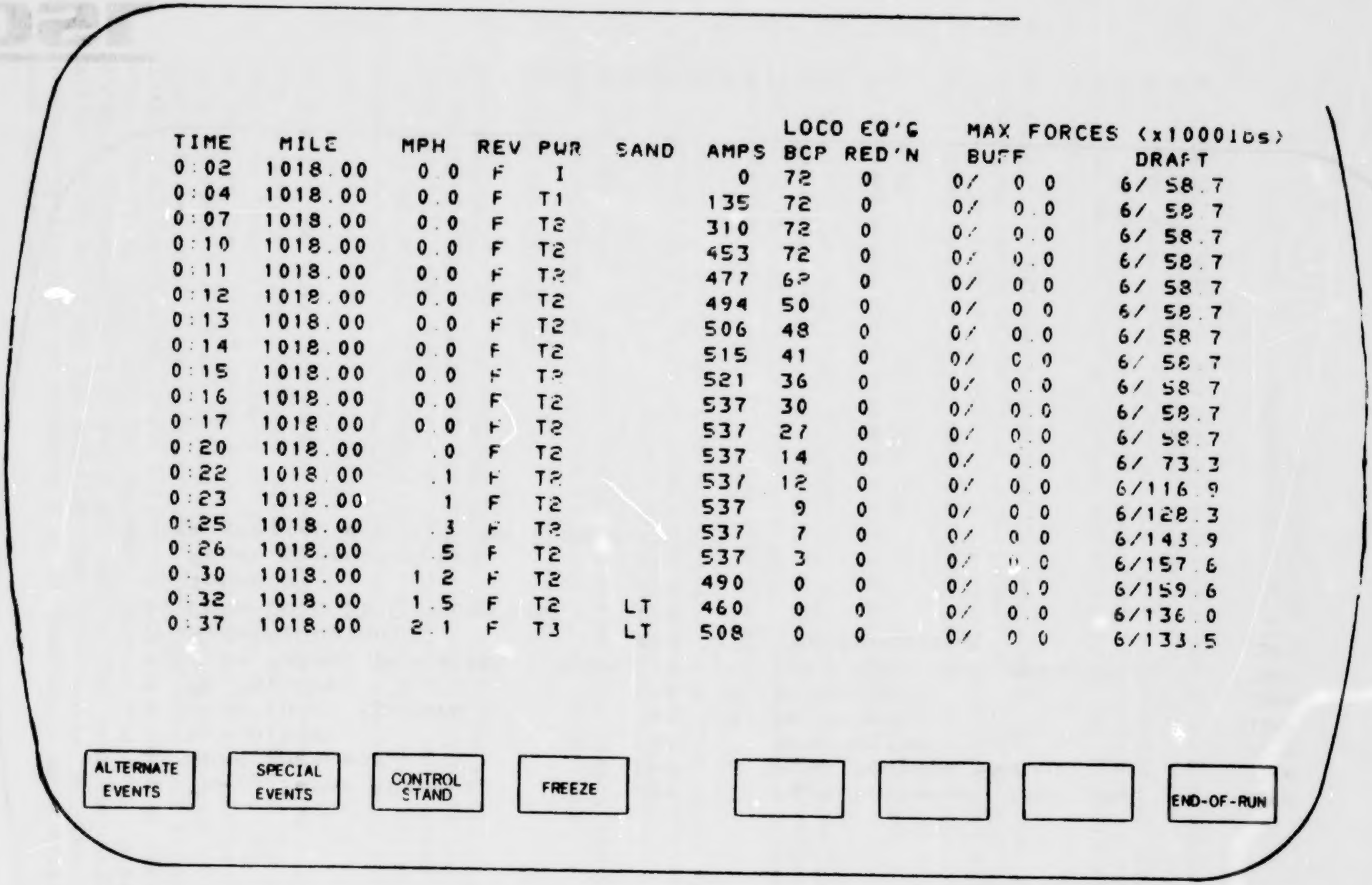
FIGURE 3 - RUN SPECIFICATION FORM



```
  50 Vehicles consisting of
   6 lead locomotives,  0 remote locomotives,
  43 loaded cars, and   1 empty cars.
  2550. ft,18000. horsepower, 3525. tons in all.
 Weight to power ratio:   1.18  horsepower/ton.
 Weight to brake ratio:  70.50 tons/brake.
```

DSL TRAIN SIMULATOR

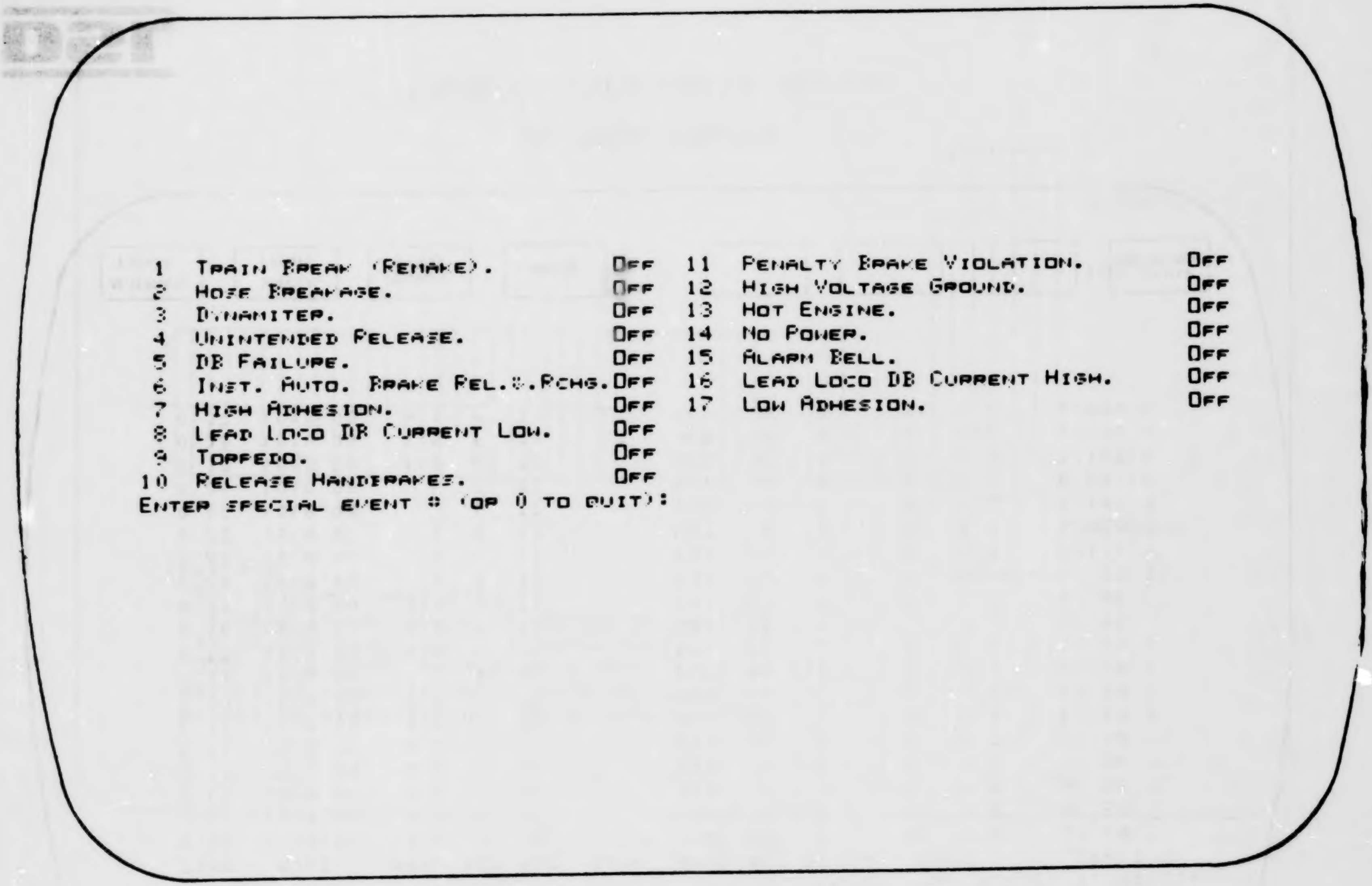
FIGURE 4 - SAMPLE CONSIST SUMMARY



```
                                                       LOCO EQ'G      MAX FORCES (x1000lbs)
TIME   MILE      MPH  REV  PWR   SAND   AMPS  BCP  RED'N     BUFF         DRAFT
0:02  1018.00    0.0   F    I              0   72    0       0/   0.0     6/ 58.7
0:04  1018.00    0.0   F    T1           135   72    0       0/   0.0     6/ 58.7
0:07  1018.00    0.0   F    T2           310   72    0       0/   0.0     6/ 58.7
0:10  1018.00    0.0   F    T2           453   72    0       0/   0.0     6/ 58.7
0:11  1018.00    0.0   F    T2           477   62    0       0/   0.0     6/ 58.7
0:12  1018.00    0.0   F    T2           494   50    0       0/   0.0     6/ 58.7
0:13  1018.00    0.0   F    T2           506   48    0       0/   0.0     6/ 58.7
0:14  1018.00    0.0   F    T2           515   41    0       0/   0.0     6/ 58.7
0:15  1018.00    0.0   F    T2           521   36    0       0/   0.0     6/ 58.7
0:16  1018.00    0.0   F    T2           537   30    0       0/   0.0     6/ 58.7
0:17  1018.00    0.0   F    T2           537   27    0       0/   0.0     6/ 58.7
0:20  1018.00     .0   F    T2           537   14    0       0/   0.0     6/ 73.3
0:22  1018.00     .1   F    T2           537   12    0       0/   0.0     6/116.9
0:23  1018.00     .1   F    T2           537    9    0       0/   0.0     6/128.3
0:25  1018.00     .3   F    T2           537    7    0       0/   0.0     6/143.9
0:26  1018.00     .5   F    T2           537    3    0       0/   0.0     6/157.6
0:30  1018.00    1.2   F    T2           490    0    0       0/   0.0     6/159.6
0:32  1018.00    1.5   F    T2    LT     460    0    0       0/   0.0     6/136.0
0:37  1018.00    2.1   F    T3    LT     508    0    0       0/   0.0     6/133.5
```

DSL TRAIN SIMULATOR

FIGURE 5 - SCREEN COPY OF TRIP LOG



```
 1  Train Break (Remake).            Off  11  Penalty Brake Violation.      Off
 2  Hose Breakage.                   Off  12  High Voltage Ground.          Off
 3  Dynamiter.                       Off  13  Hot Engine.                   Off
 4  Unintended Release.              Off  14  No Power.                     Off
 5  DB Failure.                      Off  15  Alarm Bell.                   Off
 6  Inst. Auto. Brake Rel.&.Rchg.Off      16  Lead Loco DB Current High.    Off
 7  High Adhesion.                   Off  17  Low Adhesion.                 Off
 8  Lead Loco DB Current Low.        Off
 9  Torpedo.                         Off
10  Release Handbrakes.              Off
Enter special event # (or 0 to quit):
```

DSL TRAIN SIMULATOR

FIGURE 6 - SPECIAL EVENTS AND MALFUNCTIONS DISPLAY

# DISCUSSION ON PRESENTATION BY M. KELLEY

W. SERGEANT (CANAC): Mr. Kelley has described a simulation program that allows information to be produced on how a particular train performs in the way of the dynamics of the train. Is there any potential for applying this same program even further ahead, such that it would give an output to an engineman to tell him the optimum way of handling the train he is currently running?

M. KELLEY: I believe a modification can be made to achieve that, given established limits within which he must operate. When he goes beyond those limits, some type of cue could be given to him that will tell him that what he is doing is not standard operating procedure.

W. SERGEANT: So you would see that it is necessary to make a comparison against pre-established standard operating procedures?

M. KELLEY: We have such a capability on our training simulator. This particular simulator is for research, although we have others that are similar to it that are specifically designed for training. I think what you are talking about is more for a training simulator.

W. SERGEANT: I was thinking more than that. Just imagine a simulator with an engineman at the throttle. Could the simulator tell the engineman how to handle his train such that he gets optimum dynamic performance?

M. KELLEY: Yes, if certain limits are established within the program, so that the engineman can be told he is going beyond those limits.

W. SERGEANT: Thank you.

W.S. MCLAREN (TDC): You referred to the key objective of the simulation as being the ability to model the longitudinal dynamic action in the train. At this point in time, have you been able to assess in more detail, or could you tell us about, this capability vis-a-vis real-time operation? For example, are you able to simulate long trains in real time as you had hoped to?

M. KELLEY: We have incorporated two modes, the first being real time and the second, non-real time or slower than real time. The simulation described today is an example of a real-time operation. The difference being that, because of being able only to use a VAX-11/780 instead of the original concept which was to have an array process to do some of the number crunching, we have added a slower than real-time mode that allows detailed analysis of longitudinal train action at each car. What we have done for real time is to block vehicles together, most of the time in pairs or in threes. Consequently, you don't get exactly the same longitudinal train action forces as if you had modelled them individually, but they are within engineering standards of probably 5 to 6% accuracy. So we tried to cover both applications.

C. COMISKEY (Procor Limited): You mentioned train forces which result from dynamic action in the train because one end of the train is travelling at a different rate of speed than the other end. Eventually the two ends of the train have to come to the same speed, at some very high rate of acceleration. Can you tell us what the relative speeds are of the two ends of the train in worst cases?

M. KELLEY: I am not sure that I can answer that. It depends on the type of train that you have. I think that if it has been badly marshalled, you could have severe high forces within it and that will give a variation of acceleration. I believe you are asking about velocity differences.

C. COMISKEY: Yes, the velocity differences of the two ends of the train in worst cases.

M. KELLEY: It depends on the amount of slack within the train. I cannot give you an actual number.

S. BERRADA (CN Rail); I would think that the accuracy of the results is highly dependent on how much slack you actually have between each car, and since that is variable, (it depends on how old your draft gears are or how worn your couplers are), I wonder how close to real life you can get if you just assume an average number.

M. KELLEY: The concept of the simulation program is very modular. How we deal with draft gears is that in this case we have one subroutine which would have one type of draft gear, another subroutine which would have another type. The more draft gears you have, the more subroutines. If you are talking about a particular case and you want to deal with the draft gear that has seen wear, then that particular draft gear could be added to the model. For the purposes of research, there is no limitation on the number of draft gears, or the type of draft gears you can have within the simulation.

S. BERRADA: There is also a variation in the draft gear with age and also with the coupler itself with age. Can you enter any numbers you want in terms of slack?

M. KELLEY: Yes, as I said, the vehicle and consist information is read in from files using a library format. So in the simulation, you request a particular train consist and that in turn refers you to which vehicles you want to have as part of your train. That information about the condition of that train would be incorporated under that particular vehicle.

S. BERADA: Thank you.

G.R. CATALDI (Association of American Railroads): I have two questions. First, is the modular library flexible so that you can change it; for example, have different formulas for the train resistance, as our research progresses? Or is it already fixed in and difficult to change?

M. KELLEY: It is fixed in, but it is not difficult to change,. Again, using the concept of modularity, there is a particular routine that handles drag, rolling resistance, wind resistance and curve resistance.

G.R. CATALDI: Second, have you yet, or do you plan, field verification by instrumenting a train and duplicating the train handling that you have done with the simulation to see if you are getting the forces that you have estimated?

M. KELLEY: The requirements for this job were to verify against CN's digital train simulator, so we were going to compare against existing standard simulation programs that have been verified against actual runs.

A.M. GARLICKI (NRC): I also have two questions. First, is your model for freight trains only, or is it also for passenger trains? My second question is whether you made provisions for six axle cars and a mixture of 4 and 6 axle cars in a consist.

M. KELLEY: The answer to question one is that it only handles freight trains. In your second question, do you mean six axle cars or three axle trucks? It does not handle six axle cars, although there is no reason not to modify it. It is capable of modifications to handle that particular vehicle type.

# TRAIN RESISTANCE FIELD TESTS: INTERIM RESULTS

G.W.English, Senior Research Engineer
and
J.D.Young, Research Engineer
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Kingston, Ont.

## ABSTRACT

CIGGT is currently carrying out a project to obtain and analyze detailed train resistance data from revenue train operations. The project is being funded by Transportation Development Centre of Transport Canada. CN Rail has provided cooperation and assistance in the collection of the data. NRC has cooperated in providing anemometer calibration and instrumentation.

Eight runs of Toronto-Montreal intermodal trains were recorded on analogue tape. These data were then digitized for analysis on a personal computer. The data recorded included speed, drawbar force, wind speed and direction, throttle position, train line brake pressure, locomotive independent brake pressure and track gradient. Sections were identified for coast-down and acceleration tests.

Two types of intermodal cars were tested:

- an older single platform car
- a low profile articulated "5-pack" car.

The data collected for the eight runs will allow an examination of the effects of bearings, track quality, trailer spacings and car configurations on train resistance. The data will be used in an attempt to validate theoretical, laboratory and wind tunnel investigations of train resistance.

The data collected have been digitized and reduced, and statistical analysis initiated. Problems were apparent with the gradient data for the test segments. Currently, work on the project involves obtaining new gradient data for the test sections in order that the grade resistance portion of the train resistance can be factored out with confidence.

# TRAIN RESISTANCE FIELD TESTS: INTERIM RESULTS

## OBJECTIVES

This paper presents the status of an ongoing investigation of train resistance being performed for the Transportation Development Centre. The objectives of this project are to provide validation data for the various theories of train resistance to motion and at the same time to evaluate the effectiveness of using revenue train runs as a data source.

## TEST PROCEDURE

The testing was done in conjunction with CN Rail's Operations Department who were carrying out comparative train resistance tests on old and new intermodal cars between Toronto and Montreal in August 1985. Eight test runs were made -- three runs with older piggyback cars and five runs with new "5-pack" style cars. These test runs alternated between Toronto and Montreal. Each test consist included two GP40-2 locomotives, a CN dynamometer car (#15100), 55 intermodal cars, and a caboose.

Anemometers record wind speed and direction acting on the locomotive. Two propeller-generator anemometers were attached to the front of the leading locomotive on a boom. A $1/12^{th}$ scale model of the locomotive was placed in the National Research Council's (NRC) Low Speed Wind Tunnel in order to examine the effect of the locomotive's front shape on the anemometer calibration.

The dynamometer car is equipped with a strain-gauged draft gear assembly which measures drawbar buff and draft. A pressure transducer is installed in the locomotive air-brake reservoir in order to determine locomotive independent brake pressure. The dynamometer car is equipped to measure train-line brake pressure and its own cylinder pressure. From a 27-pin, multiple-unit cable attached to the locomotives, the dynamometer car measures throttle position. The dynamometer car also records train speed, gradient and milepost (through an event marker).

As the on-board instrumentation is limited to a multi-pen strip-chart recorder, a Honeywell Model 101 Data Tape Recorder was installed on the car to record the following parameters:

- anemometer voltages
- train speed
- draw bar pull
- gradient
- milepost
- brake pipe pressure
- locomotive independent brake pressure
- test car brake cylinder pressure.

Prior to the start of testing, the line was examined in order to determine level or constant grade sections suitable for acceleration and coast-down testing. For each direction, three or four sections were selected.

Before each run, the length and gap spacing of each piggyback trailer on the train was measured using a sonic distance measuring device. Each piggyback trailer was weighed as well. This will be combined with the empty car weight in order to calculate the total train weight.

To permit analysis of energy dissipation in the suspension system, measurements of the track condition were made. This was accomplished using data obtained from CN's track geometry car (#15000). The geometry car measures crosslevel, left rail surface, right rail surface, curvature, gauge and superelevation. The Honeywell 101 tape recorder was placed on board to record these parameters over the track section.

The analog tape recordings made on both the geometry and dynamometer cars were digitized using a personal computer to permit easier evaluation of the data.

## DATA REDUCTION AND VALIDATION

The validation stage led to a number of adjustments. The train speed indication was adjusted according to the manual milepost markers. Then train speed and measured air speed were compared under calm conditions. The calibration factor derived in the scale-model wind tunnel had to be adjusted with a 12 per cent speed proportional factor.

The corrected air speed indication then compared favourably with weather reports for the other test runs. The on-board inclinometer was found to have unacceptalbe repeatability to the accuracy required for grade estimation. A separate data file of gradient profile based on a ten-year-old survey of the line was used instead.

The data reduction focussed on two areas. The effects of potential and kinetic energy changes on train resistance were factored out of the dynamometer car data; also the track geometry car data was passed through a Fourier transformation to obtain power spectral densities (PSD) for surface, cross-level and alignment variations.

## DATA ANALYSIS

This stage of the project is currently active. A regression analysis of the data has uncovered evidence of errors in the track gradient data. Figure 1 illustrates the correlation of the residuals or errors in the actual data in relation to the least square regression curve fit with the track gradient profile.

There is a direct correlation of all large errors. A field inspection of various track test segments has confirmed that the gradient data file is in error.

This represents the current status of the work. We are awaiting approval to undertake a new gradient survey of the line in order to accurately factor gradient forces out of the data.

## CONCLUSIONS

While the early stages of data analysis do not permit any conclusions on train resistance at this time, we have found that revenue trains can provide a reasonable and inexpensive data soruce for train resistance investigations. However, it is important to have a defined test segment where the subject trains can be accelerated through as wide a speed range as possible and to have an accurate survey of the gradient profile on the test segment. We are confident that the data analysis will be quite informative once the gradient forces are accurately factored out.

## ACKNOWLEDGEMENTS

The authors would like to thank CN Rail, and in particular Mr. Jim Gussow of the Operations Department for his cooperation in the dynamometer car test runs and Mr. Don Holfeld of the Engineering Department for his cooperation in the track geometry car runs. The assistance of the NRC's Railway Laboratory and the Low Speed Aeronautic Lab in the course of the study is also appreciated. Finally, the support of the Transportation Development Centre via Messrs Nishizaki and McLaren made the project possible.

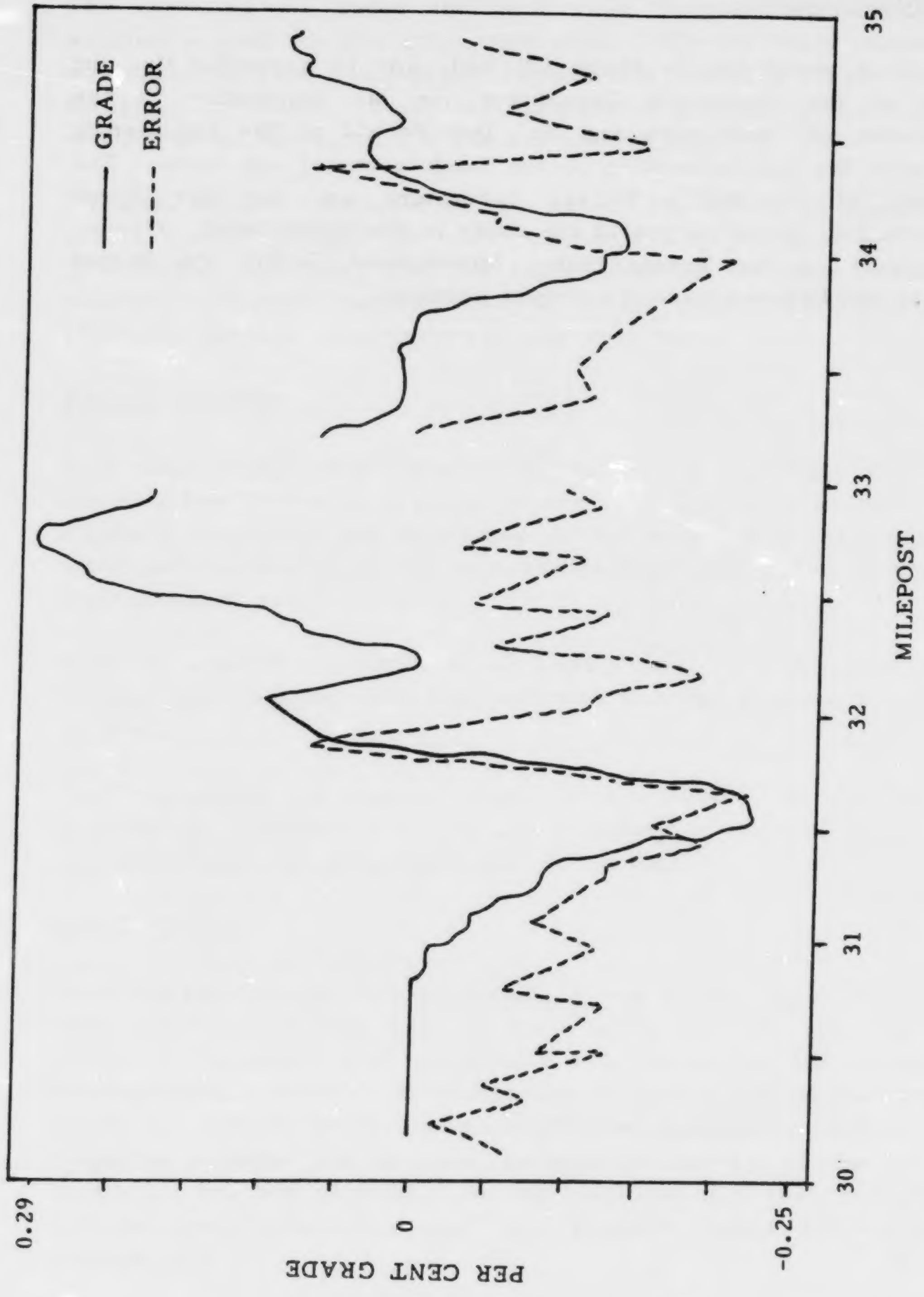

FIGURE 1

# DISCUSSION ON
PRESENTATION BY G.W. ENGLISH

No questions asked.

# TRAIN AERODYNAMICS

Kevin R. Cooper
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National Research Council
Ottawa, Ont.

## ABSTRACT

The intention of this paper is to quantify the aerodynamic behaviour of trains in the open and in tunnels. The main emphasis is on energy conservation through reduced aerodynamic drag design and on safety through an examination of overturning due to wind action. The energy question, particularly, is decided by small differences between large numbers and so demands accurate test results and a realistic analysis using the test data for meaningful economic predictions. The application of wind tunnel measurements is discussed with these ultimate needs in mind.

# TRAIN AERODYNAMICS

## ABSTRACT

This paper is a view of rail vehicle aerodynamics taken from the aerodynamicist's perspective. The intention is to quantify the aerodynamic behaviour of trains in the open and in tunnels. The main emphases will be on energy conservation through reduced aerodynamic drag design and on safety through an examination of overturning due to wind action. The energy question, particularly, is decided by small differences between large numbers and so demands accurate test results and a realistic analysis using the test data for meaningful economic predictions. The application of wind tunnel measurements will be discussed with these ultimate needs in mind.

## 1.0 INTRODUCTION

Good aerodynamics design is recognized as important to the performance of high speed passenger trains (Ref. 1) and now it is becoming apparent that aerodynamics may also have a significant impact on low speed freight trains (Ref. 2) and urban transit vehicles (Ref. 3).

Aerodynamic influences usually affect performance or safety, and may do so through one or more of the following mechanisms.

1) **Aerodyanmic Drag**
- top speed, acceleration and, therefore, trip scheduling
- fuel or energy consumption
- tunnel effects

2) **Aerodynamic Rolling Moment**
- wind-induced overturning
- ride comfort

3) **Aerodynamic Side Force**
- increase of rolling friction (?)

4) **Internal Flows**
- engine cooling
- traction motor, brake and bearing cooling
- airconditioning and ventilation

5) **External Flows**
- pressure pulses due to tunnel transit
- cargo loss
- snow accumulation

This paper will consider the first two items in some detail, with the last three only mentioned for completeness. The discussions will be prefaced by a summary of rail vehicle aerodynamics, and will emphasize wind tunnel testing technology because the wind tunnel is the major, and most cost-effective, tool employed for the aerodynamic investigation and development of rail vehicles. The techniques by which wind tunnel measurements are extrapolated to the full scale vehicle operating in a windy environment will also be examined. Finally, several examples will be quoted to demonstrate the range of possible aerodynamic effects.

## 2.0 THE WIND TUNNEL

Because the wind tunnel and its predictions form the main thrust of this paper it is appropriate to commence with a discussion of the wind tunnel's capabilities.

Most of the flow over a train is generated by its own movement. One may wonder, then, why aerodynamics studies cannot be done on the track? They can, of course, but are subject to the usual difficulties of full-scale observation: lack of precise environmental measurement and control, the difficulty of making accurate measurements on a moving, vibrating platform, and the difficulty of separating aerodynamic forces from those of other origin. With sufficient preliminary laboratory testing, comprehensive instrumentation, much care, and many test repetitions, it is possible to obtain good-quality aerodynamic data on the track under low-wind conditions. Typical measurements would include deceleration runs, engine power, or draw-bar pull, for aerodynamic drag evaluation. The time and expense required for such testing precludes its use in routine aerodynamic configuration development. Further, the small successive improvements that are the usual route to a given aerodynamic performance goal may be difficult or impossible to discern.

In order that the wind tunnel represent track behaviour exactly, the wind-tunnel flow and model simulations must be chosen such that the model's external flow field in the tunnel faithfully represents real life. The reality of the situation is that wind-tunnel simulations only approximate this ideal and, for this reason, one cannont expect the magnitudes of the measured forces to be identical to full scale. Experience has shown, however, that the differences between configurations predicted from the wind tunnel measurements are considerably more accurate than the absolute magnitudes. The wind tunnel is such a powerful tool precisely because these **differences** are most necessary to determine the **optimum** aerodynamic geometry and to estimate the performance benefits that will accrue from them.

## 2.1 Ground Simulation

A most important and thorny problem for rail vehicles is the need to represent the train-ground interface with a non-moving model. Early tests avoided this problem by suspending models in the middle of the tunnel, away from the floor. It was soon realized that this was inadequate, and a series of ground-simulation techniques were devised. These included the use of two mirror-image models, testing near the tunnel floor, testing on a separate groundboard, testing over a moving belt, and the recent development of testing over a porous floor. In each instance, the installation was designed to reduce or remove the layer of stagnant air near the ground surface that builds up due to friction as the air flow in the wind tunnel moves over the fixed tunnel floor. This is not a major problem for most surface vehicle testing but an incorrect boundary simulation has the potential to produce large drag errors for rail vehicles because much of a train's drag comes from the underbody and bogie assemblies. Placing them in the slower air flow of the "boundary layer" on a fixed ground simulation will serve to reduce the underbody drag contributions. Fixed ground simulations are probably only adequate for short train consists and for the development of the upper body shape. The moving ground avoids these problems since it travels at the air speed and so no boundary layer is formed. However, it is complex, expensive and demands model mounting struts that can interfere with the flow. The newest concept, a porous floor, seems most promising. Here, the boundary layer is sucked off just as it forms. This technique needs further development but offers considerable potential for accurate measurements, even with long models.

## 2.2 Reynolds Number Effects

One of the major problems in drag measurement arises because of the differences between model and full-scale Reynolds numbers. The Reynolds number is a dimensionless aerodynamic similarity parameter that, ideally, should be the same at model scale as at full scale. It is defined by:

$$\mathbf{Re} = \mathbf{V_r \ell / \nu} \qquad (1)$$

where $V_r$ is resultant air speed, m/s
$\ell$ is the reference length, m
$\nu$ is kinematic viscosity ($1.46 \times 10^{-5}$ m$^2$/s at STP)

As can be seen, it is the product of a characteristic length, for example train width, w, or length, and the resultant air speed. Thus, with a 1:10 scale model the wind tunnel test speed should be 10 times full scale - beyond most tunnel's capabilities and approaching supersonic flow speed.

When most of the aerodynamic drag is due to pressure drag, a value of Reynolds Number between one and two million, based on width as reference length, is sufficient to produce the same flow as at full scale, in which case the exact scaling of Reynolds Number is not required. However, when skin friction is a major contribution to drag, as is ususally the case on trains longer than two or three cars, a problem arises because the skin friction factors for the same relative surface roughnesses are different at model and full scale. The full scale train would be expected to have lower skin friction coefficients because of its higher Reynolds number than the scale model. The only corrective action possible would involve post-test data adjustments. The basis on which these adjustments should be made is not clear. Extensive model and full scale measurements of skin friction would be required to develop a proven adjustment procedure.

The end result is that the wind tunnel will predict nose and tail shape effects accurately as well as the influence of body shape. It should also allow the development of optimum bogie streamlining through comparative testing, but will not provide correct full scale drag values. Thus, if the economic benefit of a modification appears marginal the wind tunnel measurement may not predict this benefit, or loss, sufficiently accurately using current technology for a reliable engineering decision on equipment selection. Here is a case where full-scale validation testing is imperative.

Finally, the wind tunnel is not able to simulate the aerodynamics of a train passing through a tunnel. Nor will pumping air through a model tunnel suffice because the pipe flow resulting from the wall boundary layers is totally unlike the flow experienced by a train in a tunnel. Here we have the ground simulation problem not only beneath, but also completely surrounding, the train. The only solution is to propel a model train through a model tunnel or to use approximate theoretical methods for the aerodynamic drag evaluation.

## 2.3 Wind Effects

A rail vehicle is usually exposed to a variable, gusty wind that continuously changes in speed and direction. At any instant the wind velocity vector can be considered as the sum of a mean and a fluctuating gust component. The steady, mean wind increases in speed from zero at ground level to a maximum value hundreds of meters above the ground. The unsteady fluctuating part consists of a series of random gusts distributed normally about this mean value. If the wind is blowing at an angle $\phi$ to the direction of the train's motion it will produce a resultant air speed different from the ground speed and will cause a resultant wind direction which is yawed relative to the train's direction of motion. Currently, the wind gusts cannot be simulated properly in the wind tunnel and, since they are usually small compared to the mean resultant air speed, they are ignored. Only the mean flow is simulated by the smooth flow in the wind tunnel. The magnitude of the mean yaw angle is given by:

$$\Psi = \tan^{-1}\left[\frac{(V_W/V)\sin\phi}{1 + (V_W/V)\cos\phi}\right] \text{ deg} \qquad (2)$$

where $V$ is the train speed on the rails, m/s

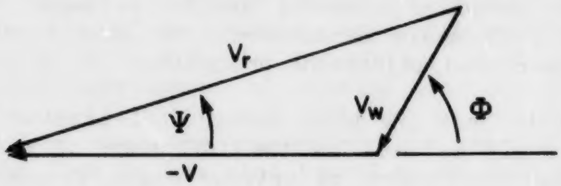
$V_W$ is the wind speed, m/s

$\phi$ is the angle between the train heading and the wind vector, deg.

The resulting mean air speed is given by

$$V_r = V \left[ 1 + (V_W/V)^2 + 2\,(V_W/V)\cos\Phi \right]^{1/2} \quad \text{m/s} \qquad (3)$$

as shown in the following vector diagram.



Although the mean wind may vary appreciably over the height of the vehicle the deviation of the resultant speed and yaw angle over the height of the train would be only a few percent above and below the mean values at the train mid-height (about 3 m above the ground) at typical speeds. Thus it is a reasonable approximation to simulate the resultant air speed with the uniform wind tunnel flow and the resultant yaw angle with a constant angle obtained by rotating the model about a vertical axis in the tunnel.

The random variations in the mean wind are not catered for explicitly in a test. Tests are performed at a series of yaw angles and the statistical variations in mean wind direction can be accounted for using a wind-averaging analysis that will be outlined in a later section.

## 3.0 FLOW COMPUTATION

As has been seen, the wind tunnel is not a perfect analogue of the full-scale situation. It is, as has already been stated, the best tool currently available. Flow computation is sometimes offered as an alternate to the wind tunnel but current technology is totally incapable of computing the viscous flow over the immensely complex bluff shape of a train. Flow computation is a powerful tool for streamlined aircraft shapes where the flow is attached and lift is of primary importance. It has serious problems when facing geometries, like trains, with large regions of flow separation where drag is the focus. Numerical computation can be a powerful adjunct to experiment, but cannot stand alone. Its current capability is best exercised in such tasks as computing local details such as optimum leading edge shapes where the flow is attached.

## 4.0 MOVING TRAIN MODELS

An alternative to the wind tunnel or to flow computation would be the use of a moving model propelled over a model track. This provides a correct flow and ground simulation and, with the provision of properly designed gust generators, could also model the wind effects exactly. Such a simulator could also be used for the dynamic modelling of truck instabilities and could be a powerful though complex and expensive facility. Finally, full-length trains could be evaluated, and this simulator would allow the unsteady flow effects (drag, pressure pulses) when entering and passing through tunnels to be examined. Model-scale Reynolds number problems would still be present.

## 5.0 AERODYNAMIC CHARACTERISTICS

As a preface to discussions of the aerodynamic drag force and the aerodynamic rolling moment, the concept of the "aerodynamic coefficient" will be introduced. In the following discussions, the term "aerodynamic force(s)" will be taken to include moments also.

Aerodynamic forces are functions of vehicle shape, size and relative air speed. The term "relative" is important as it includes the combined effects of train and wind motion. In order to make aerodynamic measurements generally useful, whether from models in a tunnel or a real train on a track, it is useful to be able to remove the size and test speed effects, retaining only the shape effect. This is done through the reduction of the measured aerodynamic forces to dimensionless (no units), universal, aerodynamic coefficients. These coefficients reflect shape alone and, at any given Reynolds number, are speed independent. The general force and moment coefficients are defined through the forces and moments as:

$$F = qAC_F \qquad \mathrm{N} \tag{4}$$

$$M = qA\ell C_M \qquad \mathrm{Nm} \tag{5}$$

where $F$ is the aerodynamic force, N
$M$ is the aerodynamic moment, Nm
$q$ is the dynamic pressure of the resultant airflow, $1/2\ \rho V_r^2$ N/m$^2$
$A$ is the reference area, commonly frontal area, m$^2$
$\ell$ is a reference length, commonly train width, m
$V_r$ is the resultant air speed, m/s
$\rho$ is the density of air, 1.226 kg/m$^3$ at STP

These equations can be inverted to obtain the necessary coefficients, as done below for drag and rolling moment.

$$C_D = D/(qA) \tag{6}$$

$$C_{RM} = RM/(qA\ell) \tag{7}$$

Once the coefficients have been determined from wind tunnel measurements, using Equations (6) and (7), then they can be extrapolated to the forces for any speed at full scale by applying Equations (4) and (5). Often because an accurate measure of frontal area is difficult to make, the drag is quoted at full scale as "drag area", given as:

$$C_DA = D/q \qquad \mathrm{m}^2 \tag{8}$$

This useage, which removes the requirement to measure frontal area, allows a direct comparison of the aerodynamic drag of different trains. Another convention that may be used is the assumption of a constant value of 9.3 $m^2$ (100 $ft^2$) for the frontal area, again allowing a direct comparison of drag for different sizes and shapes through a constant-area-based drag coefficient.

## 5.1 Aerodynamic Drag in Open Air

The aerodynamic drag force on a train stems from two major sources - pressure drag and skin friction. Pressure drag is a result of the pressure difference acting across the front and rearward facing components of the train. Skin friction results from viscous energy dissipation as the flow "rubs" along the train's surfaces. Pressure drag is significant on the front and rear faces of the train, on any open or truss-work cars, in the gaps between cars, and on the bogies and wheels. Skin friction is of major importance on the external surfaces of the train parallel to the direction of motion and, in this paper, includes the total drag-producing effects of any surface projections such as external ribs.

It is possible, then, for drag to be reduced through shape changes that reduce pressure drag, and through improvements in surface finish (smooth windows, no external ribs) that reduce skin friction. The proportions of the different drag components in a train will depend on its design. A breakdown for high and low drag, 14 car passenger trains (Ref. 1), typical of European and North American stock, is given in Table 1. Both trains have similar proportions of shape-related and surface-finish drag, with the improved shape and smoother exterior of the low drag train clearly evident through lower pressure drag and skin friction, respectively.

**TABLE 1: High and Low Drag Passenger Train Aerodynamic Drag Breakdown**

| SOURCE | HIGH DRAG | | | LOW DRAG | | |
|---|---|---|---|---|---|---|
| | % total | $C_DA$ ($m^2$) | $C_D$ | % total | $C_DA$ ($m^2$) | $C_D$ |
| **Pressure** (nose, tail, gaps) | 14.5 | 4.5 | 0.48 | 8.0 | 1.3 | 0.14 |
| **Pressure** (bogies) | 42.0 | 12.9 | 1.39 | 46.5 | 7.7 | 0.83 |
| **Skin friction** (sides, roof) | 24.5 | 7.5 | 0.81 | 27.0 | 4.5 | 0.48 |
| **Skin friction** (underbelly) | 11.0 | 3.4 | 0.37 | 7.5 | 1.2 | 0.13 |
| **Miscellaneous** (grilles, pantograph) | 8.0 | 2.5 | 0.27 | 11.0 | 1.8 | 0.19 |
| **TOTAL** | 100.0 | 30.8 | 3.32 | 100.0 | 16.5 | 1.77 |

The author does not have a similar breakdown for typical North American freight trains but it is expected that the proportions will be similar, although the total aerodynamic drag will be much higher due to greater train length, due to the rougher external surfaces, and due to the more square-edged cars employed. While a detailed drag breakdown is not available, the overall drag levels are reasonably well known, mainly as a result of recent wind tunnel investiagations sponsored by the Association of American Railroads (Ref. 4,5). In these tests the effects of side winds, in-train position, car and locomotive geometry, and car, trailer or container spacing were investigated. The results indicated:

1) drag decreased initially with car position, becoming nearly constant by about the eighth car

2) drag increased with increasing spacing between cars or components

3) for cars past the first few, drag was virtually unaffected by yaw angles of 10° or less, induced by moderate winds.

Table 2 contains a summary of some of these aerodynamic drag measurements.

**TABLE 2: Freight Train Drag Breakdown ($A=9.3\ m^2$)**

| VEHICLE | $C_DA$ ($m^2$) | $C_D$ |
|---|---|---|
| Std GM SD-60 Locomotive | 12.03 | 1.29 |
| Low Drag GM Locomotive | 9.91 | 1.07 |
| GE C39-8 Locomotive | 13.02 | 1.40 |
| Wide Hood CN Locomotive | 10.83 | 1.17 |
| Empty Gondola | 3.72 | 0.40 |
| Loaded Gondola | 2.79 | 0.30 |
| Smooth-Sided Empty Gondola | 3.16 | 0.34 |
| Auto Rack | 3.72 | 0.40 |
| Containers | 2.97 | 0.32 |
| 12 m Trailers | 5.57 | 0.60 |
| Cooling airflow drag | 4.92 | 0.53 |
| Additional for rear vehicle | 0.93 | 0.10 |

The drag levels in Tables 1 and 2 can be used to define three high-drag/low-drag sets of trains - passenger, freight, and urban transit - for reference in later calculations. Their properties are given in Table 3.

**TABLE 3: Characteristics of Typical Trains**

| TRAIN | CONSIST* | NO. AXLES | WEIGHT (N) | POWER (kw) | $C_DA$ ($m^2$) | $W/(C_DA)$ ($N/m^2$) |
|---|---|---|---|---|---|---|
| Passenger | 2 + 12 | 56 | $7.33 \times 10^6$ | 5200 | 31 | $2.36 \times 10^5$ |
| Passenger | 2 + 12 | 56 | $7.33 \times 10^6$ | 5200 | 17 | $4.31 \times 10^5$ |
| Empty Open Unit Gondola | 4 + 100 | 424 | $3.77 \times 10^7$ | 10700 | 426 | $8.85 \times 10^4$ |
| Empty Covered Unit Gondola | 4 + 100 | 424 | $3.77 \times 10^7$ | 10700 | 333 | $1.13 \times 10^5$ |
| Loaded Unit Gondola | 4 + 100 | 424 | $1.27 \times 10^8$ | 10700 | 333 | $3.81 \times 10^5$ |
| Urban Transit | 3 | 12 | $1.86 \times 10^5$ | 720 | 7 | $2.66 \times 10^4$ |
| Urban Transit | 3 | 12 | $1.86 \times 10^5$ | 720 | 4 | $4.65 \times 10^4$ |

* locomotives + cars

The right-hand column determines the magnitude of the aerodynamic drag relative to the rolling resistance, which is proportional to weight. Trains with small values of $W/C_DA$ will exhibit peformance that is more influenced by aerodynamic drag than those with large values.

## 5.2 Wind Effects on Drag

The effects of wind are, on average, to increase the aerodynamic drag of a vehicle. This occurs for two reasons. Firstly, the wind can change the resultant air speed and, because of the $V^2$ effect, produces a larger drag for headwinds than a thrust for tail-winds. Secondly, the wind usually produces a yawed resultant air flow that may also increase the drag coefficient. The latter situation is only the case for short trains or for the first few cars of a long train, as demonstrated by the measurements in Reference 5. Apparently the first few cars align the flow with the train and the yaw effect is diminished.

If the wind statistics for a country, or for a specific route are known it is possible to calculate the average yaw angle and resultant wind speed effects as shown in Reference 6. The calculation procedure also allows the drag coefficient to be based on ground speed, rather than on resultant air speed, by incorporating the effects of the expected winds. The resulting, modified drag coefficient is termed the "wind-averaged" drag coefficient. It can be expressed for vehicles where the drag coefficient is constant with yaw angle ( long freight trains and streamlined high speed passenger trains) as follows:

$$\bar{C}_D = C_D \left[ 1 + (V_W/V)^2 \right] \tag{9}$$

$V_W$ is the yearly average mean hourly wind speed in m/s and is assumed to blow equally probably from all directions. It would be possible to include directional variations in the calculation as well as the probability distribution of wind speed, but a simple closed form expression for $\bar{C}_D$ would no longer be available. This more complex option may be necessary for accurate predictions with shorter trains and it is discussed in Reference 6. The simpler expression of Equation (9) is sufficient for the purposes of our later discussions. It contains the major effect, an increase of drag with increasing wind, especially at low track speeds where the wind is a significant fraction of the total resultant air speed. This may have an important effect on the evaluation of aerodynamic modifications as the wind's presence lowers the speeds at which aerodynamic influences become important. Drag is now calculated using train speed, from:

$$\bar{D} = (\rho V^2/2)\ (\bar{C}_D A) \qquad \text{N} \qquad (10)$$

and the modified wind-averaged drag area becomes:

$$\bar{C}_D A = C_D A \left[1 + (V_W/V)^2\right] \quad \text{m}^2 \qquad (11)$$

Equations (10) and (11) are convenient to use in train resistance formulae and automatically approximate the local average wind conditions through the selection of $V_W$.

The drag and yaw angle changes produced by the wind are summarized in Figure 1 where the drag increase and average yaw angle are plotted against wind/train speed ratio. Again, these calculations have assumed a constant wind of equal probability from all directions. The effects are seen to be largest for large values of $V_W/V$, that is for windy regions and/or low train speeds, indicating that slow freight trains are most affected in windy areas.

### 5.3 Aerodynamic Drag in Tunnels

When a train enters a tunnel the boundary conditions on the flow about the train are changed drastically. The train can be viewed as a loose piston displacing the air in a cylinder and, as such, can induce a flow in the tunnel as well as have "leakage" flows past itself. The flow induced in the direction of train motion through the tunnel increases drag, on the one hand, through additional friction with the tunnel walls and reduces drag, on the other hand, because of the reduced relative air speed. The part of the flow that is accelerated in the annular region between the train and the tunnel wall causes a large increase in skin friction and probably also in the pressure drag on the underbody components. The net sum of the three effects just considered can be a large drag increase, depending on train/tunnel relative size.

The drag of trains in tunnels is of importance because of the performance reduction that occurs and because of environmental problems that relate to high drag. The heat and exhaust gases (if any) rejected by the train's power plant and the heat resulting from air friction during tunnel transit may cause the tunnel temperature to rise to unacceptable levels and may also reduce air quality. The ability to assess the power requirments and the train-induced airflow are necessary in order to decide if additional tunnel ventilation is required.

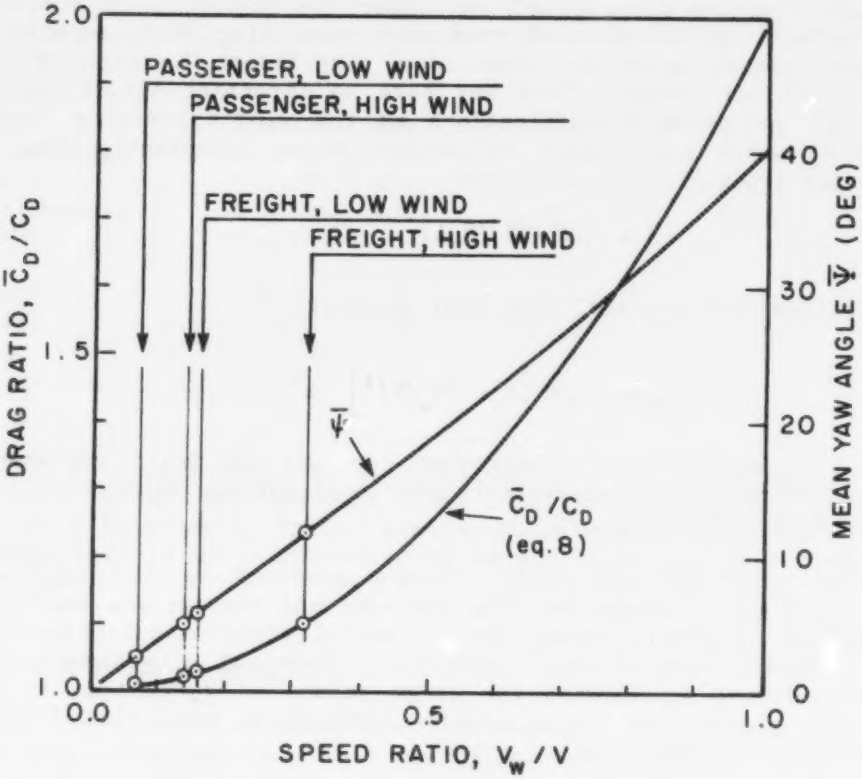


FIG. 1: WIND EFFECTS AS A FUNCTION OF WIND SPEED RELATIVE TO TRAIN SPEED

The drag in the open air, if the winds are constant, is a steady value whereas the drag during tunnel passage, at least over the entry phase, is a transient phenomenon. As the train enters the tunnel the drag increases rapidly because, initially, all the air is forced through the annulus between train and tunnel since the tunnel air is at rest. As the train moves into the tunnel, the air in the tunnel is accelerated, reducing the flow through the annulus and, because the consequent reduction of drag in the annulus is greater than the increase in the friction of the induced flow in the tunnel, the drag begins to drop. If the tunnel is long enough, the drag finally reaches a steady state value that is higher than in the open air. The distance that the train has to travel before the induced speed becomes constant depends on train and tunnel length, train drag, and tunnel size. It is typically five or more train lengths.

A simple, steady-state theory (Ref. 7,8) can be used to estimate the drag on the train once steady state conditions are achieved, that is, for transit of a long tunnel. In this instance, two equations are required to solve simultaneously for the drag of the train and for the tunnel flow rate. They are:

$$C_D = \beta(1-\sigma)^2/(1-\beta)^2 + \frac{1}{A(1-\beta)^3}\left[C_f(1-\sigma)^2 S + C_{f_t}(\beta-\sigma)\,|\,\beta-\sigma\,|\,S_w\right] \qquad (12)$$

$$C_D = C_{f_t}\,\sigma^2\,(S_t - S_w)/A \qquad (13)$$

where $A_t$ = tunnel open area (tunnel minus internal structure), $m^2$
$A$ = train frontal area, $m^2$
$\beta$ = $A/A_t$
$C_{f_t}$ = tunnel wall friction coefficient ≈ 0.005 for smooth concrete
$C_f$ = train surface friction coefficient (including underbody)
$\ell$ = train length, m
$L$ = tunnel length, m
$\sigma$ = tunnel-air-speed-to-train-speed ratio = $U/V$
$S$ = train surface area, $m^2$ (train peremeter times length)
$S_w$ = tunnel surface area (including pipes etc) **only** over the length of the train, $m^2$
$S_t$ = total tunnel surface area, $m^2$
$U$ = speed of air flow induced in tunnel by train's passage, m/s

The unknown speed ratio, $\sigma$, can be found by equating Equations (12) and (13) and iterating to a solution. Once $\sigma$ has been found $C_D$ can be obtained from either (12) or (13). When the train is in open air $\sigma=\beta=0$ so that Equation (12) reduces to:

$$C_D A = C_f S \quad m^2 \qquad (14)$$

This simplistic model indicates that the drag on the train is the skin friction only. Obviously, a discontinuity in drag will exist between Equation (14) and Equation (6) because the latter includes nose and tail pressure drag plus underbody pressure drag. A solution to the problem can be found by defining an "effective" skin friction to include these other terms. While at first sight this may seem arbitrary, it does make some physical sense, primarily because the majority of the train's drag in open air comes from skin friction and bogie pressure drag. It is a crude, but reasonable, assumption that the bogie drag terms could be included in the underbody friction by viewing the underbody and the bogies as a very rough surface. If this is done the skin friction coefficients for the trains of Table 3 can be deduced using Equation (14). The results are presented in Table 4.

Typical skin friction values measured on the sides of actual trains vary between $0.003 \leqslant C_f \leqslant 0.008$ (Ref. 8). The values presented in Table 4 are higher than these because of the inclusion of the effect of the very rough undersurface.

**TABLE 4: Effective Skin Friction Values for Tunnel Passage**

| TRAIN | $\ell$ (m) | S (m²) | $C_DA$ (m²) | $C_f$ |
|---|---|---|---|---|
| **Passenger** | 200 | 2400 | 31 | 0.013 |
| **Passenger** | 200 | 2400 | 17 | 0.007 |
| **Empty Open Unit Gondola** | 1700 | 22100 | 426 | 0.019 |
| **Empty Covered Unit Gondola** | 1700 | 22100 | 333 | 0.015 |
| **Loaded Unit Gondola** | 1700 | 22100 | 333 | 0.015 |
| **Urban Transit** | 40 | 440 | 7 | 0.016 |
| **Urban Transit** | 40 | 440 | 4 | 0.009 |

The effects of tunnel and train length on aerodynamic drag are presented in Figure 2. The train used as an example is based on the loaded gondola case summarized in Table 3. The curves are curtailed for tunnel lengths shorter than ten train lengths because transient effects would invalidate the results. Figure 3 shows the effects of tunnel size, and train and tunnel friction coefficient. It is apparent that a smooth tunnel is as important as a streamlined train. As might be anticipated, train length, tunnel length, increasing friction coefficient, and decreasing tunnel size all increase drag, with the tunnel size being a strong parameter at the larger area ratios.

The environmental problems are worst for long tunnels, for two reasons. Firstly, to maintain a given speed they produce higher train drag with the attendant higher heat input. Secondly, they have lower train-induced ventilation, just when the opposite is required. An example of this reduced ventilation effect is seen in Figure 4 for the same geometries used in the drag coefficient plots of Figure 2. Figure 4 indicates that longer trains induce a larger flow through a given tunnel length which is helpful but, as just mentioned, longer tunnels reduce this flow.

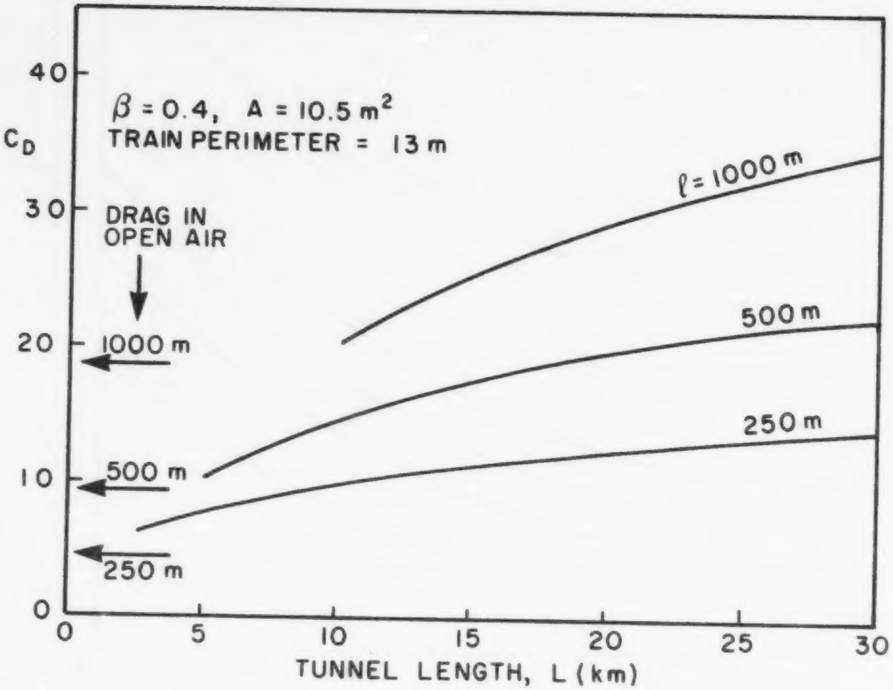


FIG. 2: EFFECT OF TUNNEL AND TRAIN LENGTH ON AERODYNAMIC DRAG

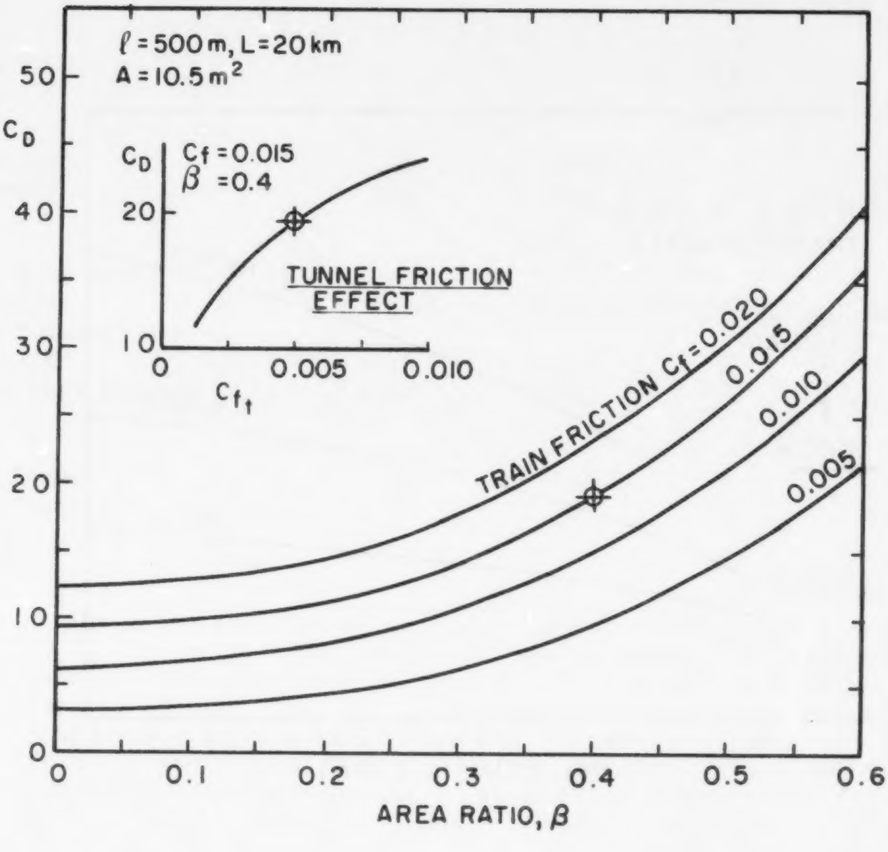


FIG. 3: EFFECT OF TUNNEL SIZE AND FRICTION COEFFICIENT ON AERODYNAMIC DRAG

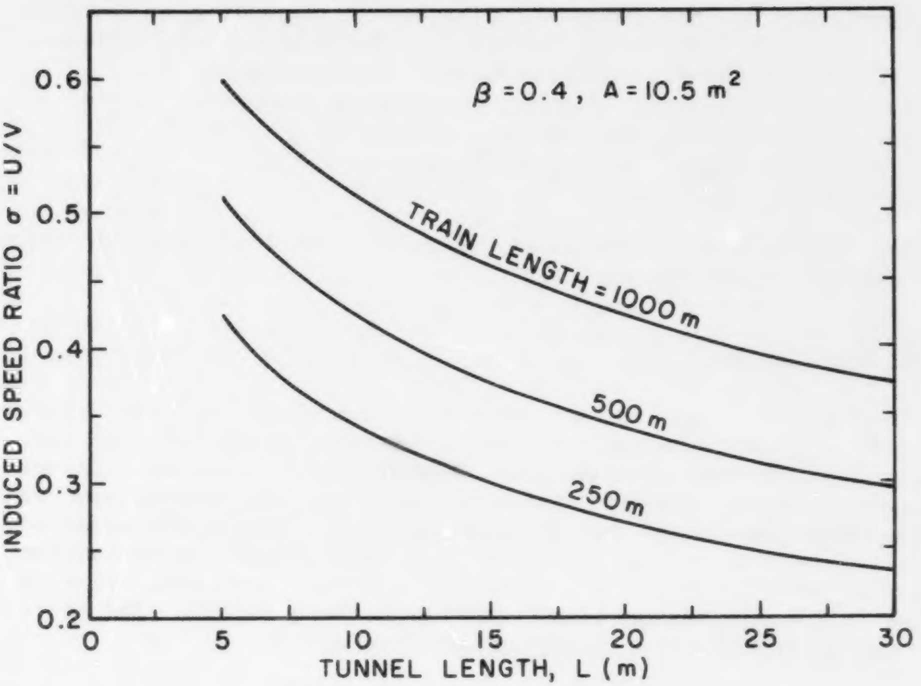


FIG. 4: EFFECT OF TUNNEL AND TRAIN LENGTH ON INDUCED AIR FLOW

## 5.4 Aerodynamic Rolling Moment

The other aerodynamic parameter to be considered in this paper is the lee-rail aerodynamic rolling, or overturning, moment. The aerodynamic side force, acting at about body mid-height, the aerodynamic lift force, acting at about one-third of the car width from the upwind side of the car, and an aerodynamic rolling moment about the mass centre all serve to apply an overturning moment about the downwind, or lee, rail. The major effect is produced by the side force which is only present when the yaw angle defined in Equation (1) is non-zero. The rolling moment varies approximately sinusoidally from zero at 0° yaw angle to a maximum value near 90° yaw angle. Typical maximum values of the coefficient are in the range $0.5 \leqslant C_{RM_m} \leqslant 1.0$, depending on vehicle shape and track or guideway design. A simple but adequate representation of the lee-rail rolling moment can be obtained from:

$$C_{RM}(\Psi) = C_{RM_m} \sin\Psi \qquad (15)$$

In some cases the rolling moment peaks below 90°, but the effect of this on overturning is negligible.

## 6.0 ENERGY UTILIZATION

Aerodynamic drag is an important component of the total resistance of a train. Its reduction will allow a combination of fuel conservation and improved productivity through higher speeds. Except for high speed trains, however, the benefits are only modest and so careful drag measurement and the analysis developed below are required to accurately determine which, if indeed any, aerodyanamic modification is economically beneficial. The resistance analysis developed below is based on the full scale measurements reported in Reference 9. The total resistance can be written in a dimensionless form as:

$$R/W = \underbrace{1.25 \times 10^{-3}}_{\textbf{rolling resistance}} + \underbrace{(\rho/2)V_r^{\,2}\,(\bar{C}_D A/W)}_{\textbf{aerodynamic resistance}} \qquad (16)$$

where
R is the resistance, N
W is the train's weight, N
V is the ground speed, m/s
$V_r$ is the resultant air speed, m/s
$C_DA$ is the drag area, $m^2$

Using the definition of wind-averaged drag from Equation (10) we have:

$$R/W = 1.25 \times 10^{-3} + \rho/2 \; (V^2+V_w{}^2) \; (C_DA/W) \qquad (17)$$

This equation now incorporates the average effects of wind through $V_w$. The aerodynamic resistance depends on the square of velocity whereas the rolling resistance is a constant term depending only on weight. Thus, at a sufficiently high speed aerodynamic drag will dominate. The speed at which aerodynamic resistance becomes important may be taken as the speed at which the rolling and the aerodynamic resistance components are equal. That is, when (from Equation (17)):

$$V^2 = V_c^2 = 2.04 \times 10^{-3} \;\; W/(C_DA) - V_w{}^2 \quad (\mathrm{m/s})^2 \qquad (18)$$

$V_c$ m/s is the "crossover speed", the speed at which the aerodynamic drag just equals the rolling resistance. As pointed out previously, the drag density, $(W/C_DA)$, effectively the ratio of the rolling resistance to the aerodynamic drag, is the significant parameter. As $(W/C_DA)$ decreases (high aerodynamic drag and/or low weight), so the speed at which aerodynamic drag becomes the major component of resistance decreases. The values of $V_c$ as a function of $(W/C_DA)$ are plotted in Figure 5 for $V_w = 0$. The three train types of Table 3 are indicated by circles on the graph. The inclusion of the wind reduces the crossover speed by a small amount, about 7% for a 10 m/s wind, as shown in the inset graph of Figure 5.

The figure shows that both passenger and transit vehicles operate at speeds well above their crossover speeds and that freight trains operate near to, but below, theirs. It is reasonable to conclude that aerodynamic drag will be important for all three rail vehicles, and especially for the first two.

The engine power and resulting fuel consumption can be calculated from the resistance formula, Equation (17), for steady state operation, where:

$$P = (RV_t/\eta) \times 10^{-3} \qquad \mathrm{kw}$$

$$= \left[10^{-3}/\eta\right]\left[1.25\mathrm{x}10^{-6} \; WV + \rho/2 \; (V^2+V_w{}^2) \; V \; (C_DA)\right] \quad \mathrm{kw} \qquad (19)$$

$\eta$ is the power transmission efficiency factor and is used to represent both the drive system and parasitic losses. A value of $\eta = 0.85$ will be assumed in the following. Equation (19) is simplistic in its treatment because some of the parasitic losses (cooling fans, air compressors etc.) are not properly represented. It is adequate, however, for the purposes of illustrating the relative magnitude of aerodynamic and other losses and is also adequate to evaluate the fuel savings possible through aerodynamic drag reduction. Using the values of $\eta$ and $\rho$ given, equation (19) becomes:

$$P = 1.47 \times 10^{-6} \; WV + 7.21 \times 10^{-4} \; (V^2+V_w{}^2) \; V \; (C_DA) \quad \mathrm{kw} \qquad (20)$$

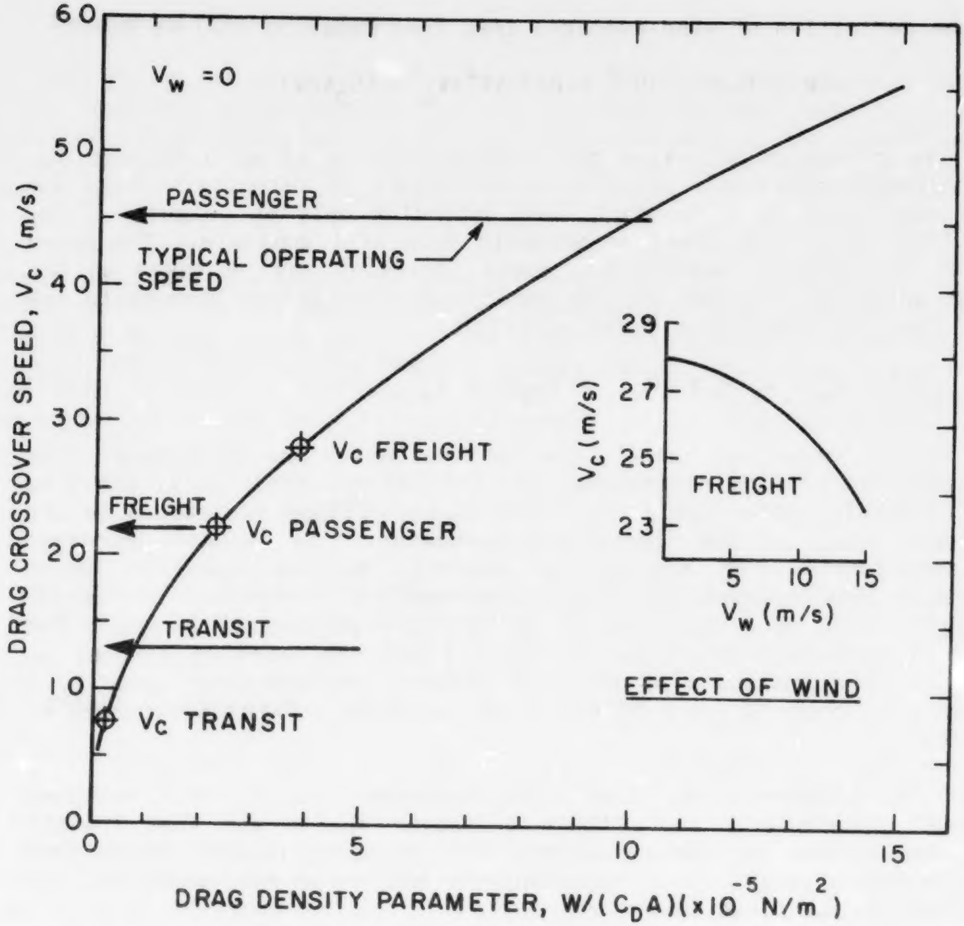


FIG. 5: RELATIONSHIP BETWEEN DENSITY AND CROSSOVER SPEED

The fuel consumed at any speed $V_t$ can be calculated from:

$$\mu = 100\ \text{SFC}\ (P/(3.6\ V)) \quad \ell/100\ \text{km} \qquad (21)$$

The change in fuel consumption due to a change in aerodynamic drag is

$$\Delta\mu = 100\ \text{SFC} \cdot (P_{std} - P_{mod})/(3.6\ V) \quad \ell/100\ \text{km} \qquad (22)$$

where SFC is the specific fuel consumption, taken as 0.275 ℓ/kw-h (0.38 lb/hp-h)

$P_{std}$ is the power required for the standard aerodynamic configuration

$P_{mod}$ is the power required for the modified, lower drag, aerodynamic configuration

Using Equation (19), Equation (21) reduces to

$$\Delta\mu = 4 \times 10^{-5}\, \Delta W + 2 \times 10^{-2}\, (V^2 + V_W^2)\, \Delta\, C_D A \quad \ell/100 \text{ km} \qquad (23)$$

where $\Delta\ C_DA$ is the change in drag area, $(C_DA)_{std}-(C_DA)_{mod}$, $m^2$ (positive for drag reduction)

$\Delta W$ is the weight change associated with the drag reduction, $W_{std}-W_{mod}$, kg (negative for weight increase)

Examples of the rolling and aerodynamic power components calculated from Equation (20) are given in Figure 6 for the three high drag trains (passenger, loaded freight, transit) of Table 3. The circled speeds at which the aerodynamic power curves cross the rolling power curves are the crossover points of Figure 5. A log-log plot is used to cater for the large range of power requirements for these three trains. In this format the power curves appear as straight lines. Rolling power, proportional to V, has a slope of +1 while aerodynamic power, proportional to $V^3$, has a slope of + 3.

The same tractive energy formula is applicable in tunnels except that the concept of the wind-averaged drag coefficient is meaningless and so $V_W$ must be set to zero when Equations (17) through (23) are used.

An interesting insight into the influence of the aerodynamic drag of freight trains is provided by Figure 7. Here, the total power required for loaded and empty unit gondola trains is plotted. The higher aerodynamic drag of the empty cars causes the total power requirements for the empty trains to exceed those for the loaded trains above some threshold speed. The two cases used as examples represent the 100 car gondola train from Table 3 and the ten car train (1 locomotive, 8 gondola cars, 1 caboose) track-tested in Reference 9. The aerodynamic drag in the latter case was taken from Reference 5 to properly represent the varying aerodynamic drag of the first few cars in the train. The speed above which the aerodynamic drag of the loaded train is exceeded by the empty train is much lower for the short train because of the large drag difference found for the first few cars (Ref. 5). This speed is shown to be 25.2 m/s for the short train compared to 26.8 m/s measured in Reference 9. The length effect becomes insignificant for trains longer than about 20 cars and they all have a similarly high value for this speed. In a way, it was fortuitous that the tests like those of Reference 9 that focussed attention on aerodynamic drag were done with short trains which show the largest effect. The low speed at which the empty train was found to have a higher total power requirement served to underscore the importance of

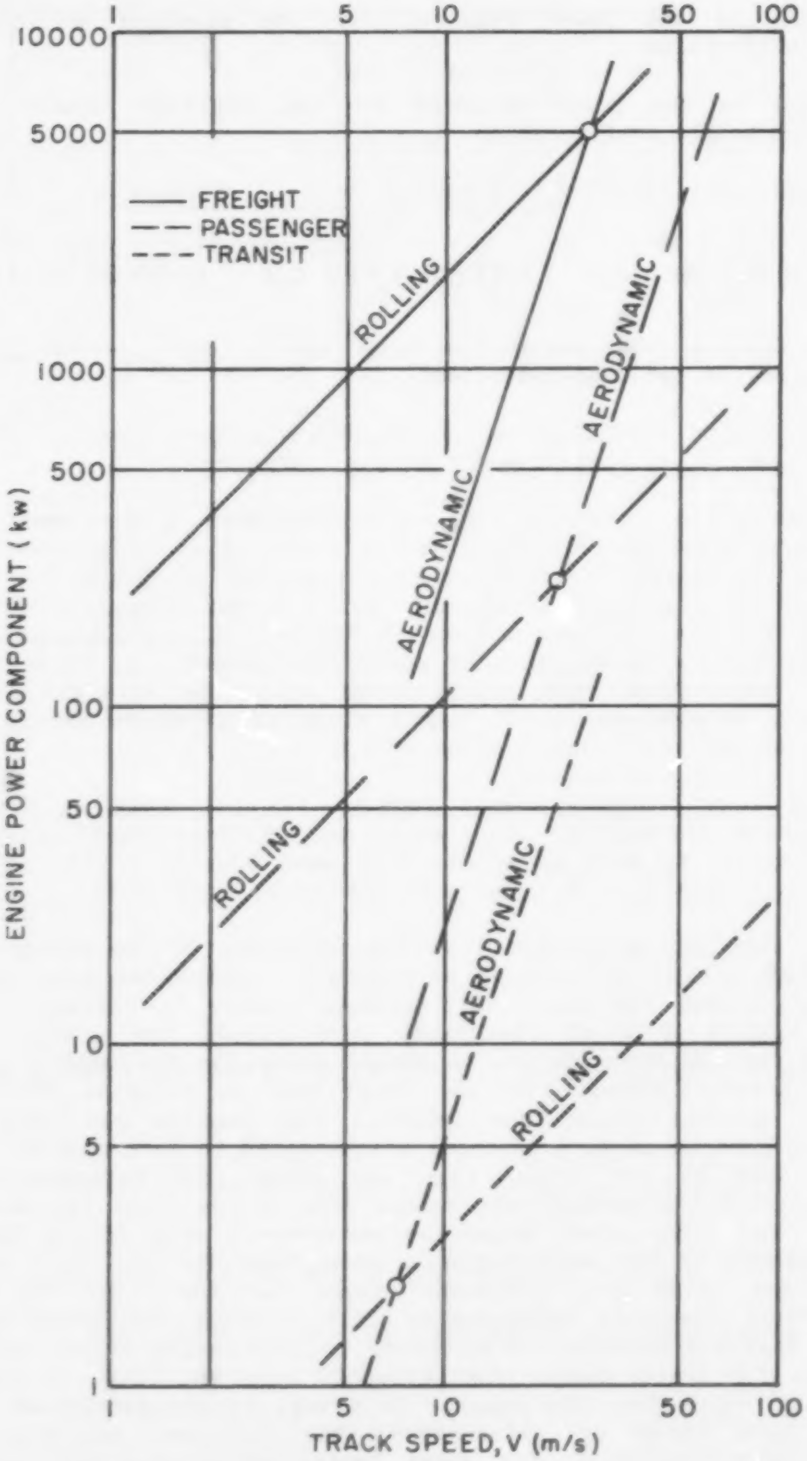


FIG. 6: RESISTANCE COMPONENTS FOR THE THREE REFERENCE TRAINS

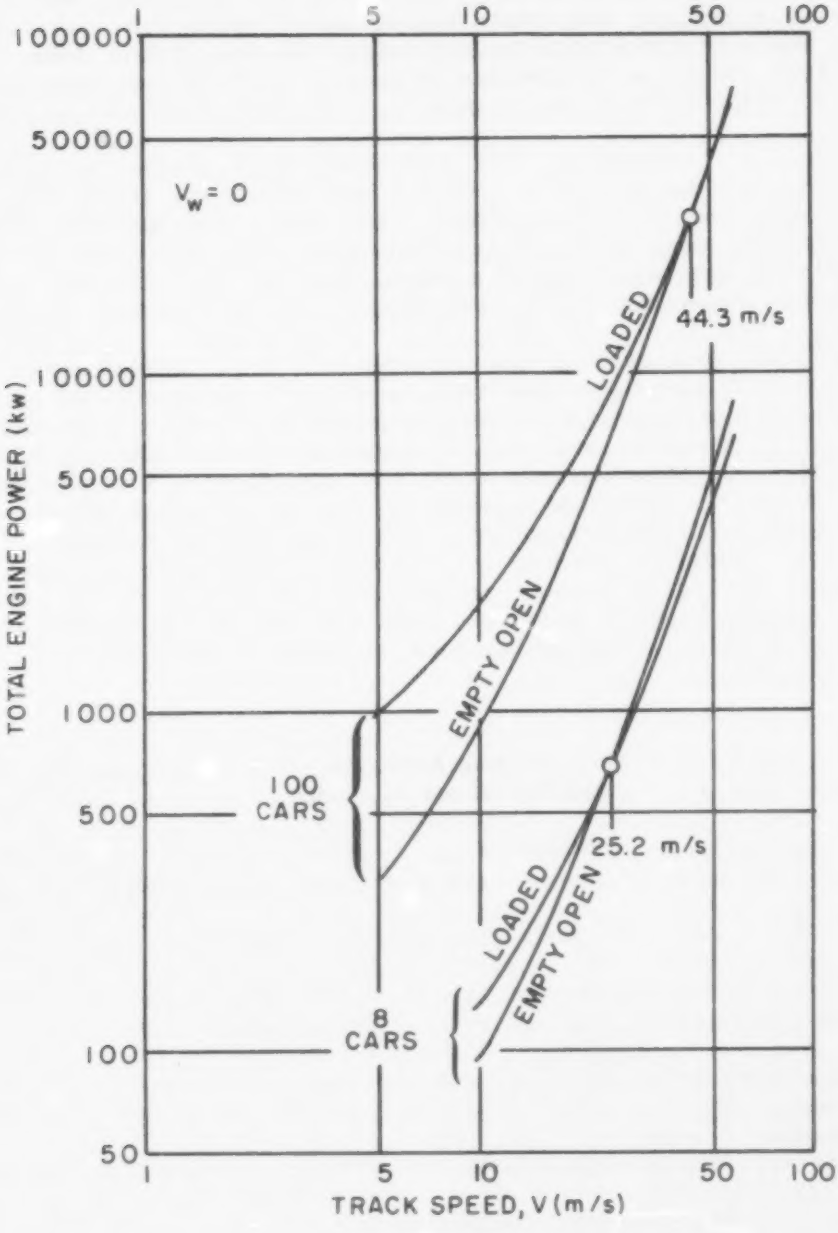


FIG. 7: COMPARISON OF POWER REQUIREMENTS FOR LOADED AND EMPTY GONDOLA CARS

aerodynamics in a fashion that the results for a longer train would not have. That the typical long train has a higher speed for equality of loaded and empty drag values does not negate the conclusion drawn from the short train tests - aerodynamic drag is important and offers the potential for significant economic gain.

The fuel consumption and top speed calculations in Table 5 were performed for the trains of Table 3 and illustrate the advantages that aerodynamic drag reduction offers. Two additional cases have been added for gondola cars with no external ribs. It is realized that transit vehicles are electrically powered, but the fuel savings quoted permit a direct comparison of the three train types.

Significant fuel savings are possible for both the passenger and freight trains - in the first case because of the high speeds and in the second because large drag reductions are possible. Whether the capital costs for the changes required to equipment and the attendant maintenance and operational costs make such modifications economically viable can only be determined through a detailed evaluation of each train and route. If the reduced drag can be used totally or partially to reduce trip times, or reduce the number of locomotives, then the resulting productivity increases, capital cost decreases, and operating cost reductions may be more beneficial than the fuel saving. The latter situation can only be resolved through a detailed simulation of the train on its route.

**TABLE 5: Effect of Drag Reduction of Fuel Saving and Top Speed ($V_W = 0$)**

| Train | $C_DA$ ($m^2$) | Cruise (m/s) | $V_{max}$ (m/s) | $\Delta C_DA^*$ ($m^2$) | $\Delta\mu^{*,**}$ (ℓ/100km) | 100,000 km$^{*,**}$ fuel saving at cruise (ℓ) |
|---|---|---|---|---|---|---|
| Passenger | 31 | 45 | 58.9 | - | - | - |
| Passenger | 17 | 45 | 71.2 | 14 | 567 | $1.13 \times 10^6$ |
| Empty Open Gondola | 426 | 25 | 30.9 | - | - | - |
| Empty Covered Gondola | 333 | 25 | 33.3 | 93 | 1162 | $1.16 \times 10^6$ |
| Empty Covered Smooth-Sided Gondola | 277 | 25 | 35.3 | 149 | 1862 | $1.86 \times 10^6$ |
| Loaded Gondola | 333 | 25 | 28.3 | - | - | - |
| Loaded Smooth-Sided Gondola | 277 | 25 | 29.6 | 56 | 700 | $7.00 \times 10^5$ |
| Urban Transit | 7 | 15 | 51.9 | - | - | - |
| Urban Transit | 4 | 15 | 62.5 | 3 | 13.5 | $1.35 \times 10^4$ |

* compared to high drag configuration

** includes a weight increase of 22500 N for 100 gondola covers

The transit vehicle's fuel savings are smaller, but are virtually free if the vehicle is designed with low drag from the outset. The high top speeds are not useable and only result from the high installed power needed for rapid acceleration. The drag reduction will serve to improve higher-speed acceleration and so may allow improved schedules or lower installed power for the same route performance.

## 7.0 DRAG REDUCTION

The intent of this paper is to explore aerodynamic influences on trains and a few brief comments on drag reduction are in order. The approaches used to reduce drag reflect the drag breakdown discussed previously and summarized in Tables 2 and 3. Four major areas are available for improvement - front and rear geometry, body surface finish, inter-car gaps, and the underbody. All four areas are treated in the latest high-speed passenger trains (HST, APT, TGV), including good nose and rear end shapes, gap seals between cars, smooth external surfaces, and bogie fairing through downward extension of the body side panels. Transit vehicles could also apply this technology although they do not generally do so yet.

Freight trains are the most difficult to deal with because of their hard service life, and because many trains are a mixture of car types. Some benefits can accrue from car and freight (container, trailer, etc.) positioning but operational constraints probably make it economically impractical to assemble trains in a low drag sequence (all boxcars together, all flatcars together, etc.). The major potential for drag reduction is through rounding the individual front and rear edges of box-like cars, through removing exterior structural posts, reducing gaps between cars, covering open cars when empty, and eventually, perhaps, developing integrated, enclosed freight trains. Currently the best opportunities would seem to be through rounding the edges of new or old stock, removing external posts, and covering open cars (hopper, gondola), expecially on unit trains. Some of these modifications could be introduced on new equipment while others might be economically feasible as a modification to existing equipment (fairings to round boxcar edges, covers on open cars). Table 6 provides an estimate of the aerodynamic drag reductions possible through these techniques. The data are taken from References 4,5,6, and 10.

It can be seen that rounded boxcars with no exterior posts and having slightly closer spacing would have a reduction in drag area of 18.5 $m^2$. Current containers are spaced too far apart for low drag and moving then closer on the car would only widen the gap to the next car's container defeating the initial gain.

The most useful technique for drag reduction for many cars will prove to be edge rounding, since rounded leading and trailing edges can be readily designed into new equipment and can be provided by simple fairings for stock already in service. It has been conclusively demonstrated that only small radii are needed to lower the drag as low as is possible even with very large fairings at yaw angles below about

10°. Reference 10 provides a sound basis for selecting the minimum required edge radius as a function of body frontal area. An analysis in the reference concludes that, on average in Canada and probably North America, a yaw angle of 9° is exceeded 10% of the time for a vehicle travelling 25 m/s and that 6° is exceeded 10% of the time at 35 m/s. Thus, good performance at small yaw angles only is of importance and is provided by modest edge rounding.

**TABLE 6: Estimated Freight Train Aerodynamic Drag Reductions**

| MODIFICATION | $\Delta\ C_DA\ (m^2)$ |
|---|---|
| Closely-spaced trailers (no gap greater than 150 cm) * | 25 |
| Streamlined trailers (round edges, fairing) | 12 |
| Reduced car separation (by 25 cm) | 2.5 |
| Rounded boxcars | 10 |
| Rounded locomotive | 20 |
| Covered gondola cars | 10 |
| No exterior posts | 6 |

* includes gap from one car to next

A design chart is developed in Reference 10 that specifies the minimum radius needed as a function of the maximum expected yaw angle. The chart is reproduced in Figure 8. The radius is presented in a non-dimentional fashion based on body size through the square-root of frontal area, which has dimensions of length. The data are valid as long as the cruising speed is above 10 m/s for typical train widths. The lead locomotive is more yaw dependent than the rest of the train so an edge radius that provides low drag up to yaw angles of 10° is needed. The following cars only need the smallest necessary radius. Assuming a 9.3 $m^2$ locomotive and a 7.5 $m^2$ box car the required radii would be:

locomotive $0.072\sqrt{9.3} = 0.219\ m = 22\ cm$

box car $0.063\sqrt{7.5} = 0.173\ m = 17\ cm$

The optimum edge shape is probably not circular since the same attached flow could be achieved with less body intrusion using a more elliptical shape. The design of such an edge shape is a task well suited to the present capabilities of computational fluid dynamics. Circular arc radii will probably still be used, however, because of their ease of fabriction.

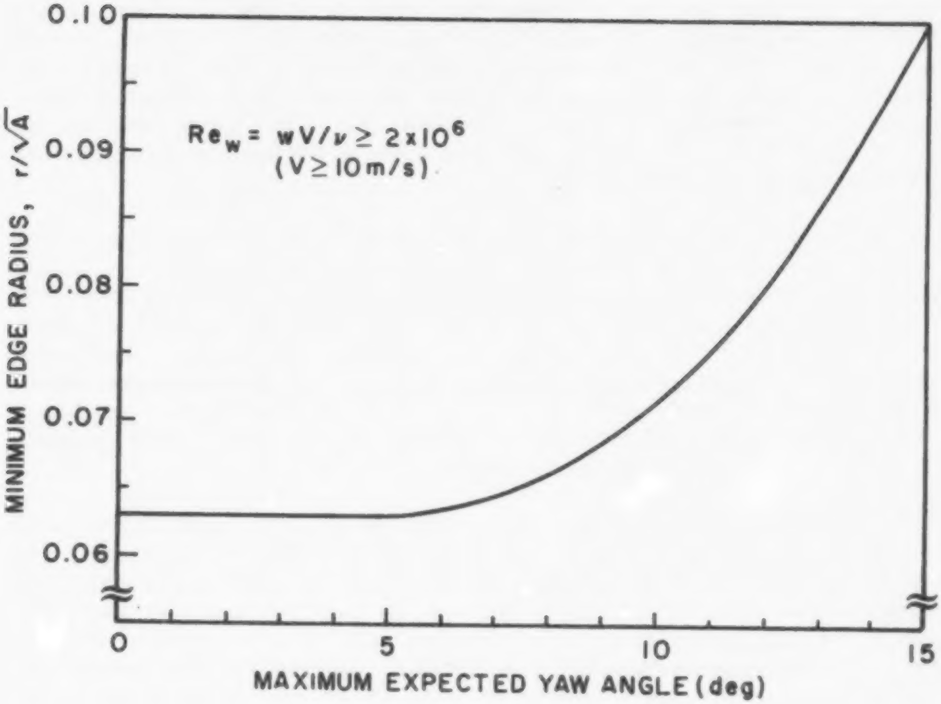


FIG. 8: MINIMUM LEADING EDGE RADIUS REQUIRED FOR LOW DRAG

## 8.0 WIND-INDUCED OVERTURNING

The wind not only raises the aerodynamic drag but it can, because of the asymmetric yawed resultant flow it induces, produce other forces and moments that can affect safe rail vehicle operation. In a side wind there is a side force, lift force and rolling moment that act singly, or in combination, to overturn the train, derail it, or lift it off the tracks. The latter two possibilities turn out to be of no real concern because extremely high wind speeds are required for their occurrence and the train would have previously overturned.

The threshold for overturning occurs when the aerodynamic rolling moment about the downwind, or lee, rail exceeds the restoring moment due to the train's weight. As soon as this happens the train begins to roll over. As it does so, the restoring moment decreases because the moment arm to the mass centre is reducing and the overturning process accelerates. It is a true static instability. Computations of the overturning dynamics in Reference 3 show that the time required for overturning is under one second. Once overturning has started, it is extremely unlikely to stop, even if the wind should diminish. Because the vehicle responds so rapidly, a short period gust is sufficient to cause overturning with the critical gust duration (Ref. 3) being about 2 seconds. The 2 second gust is large enough to completely engulf a typical rail car and has a higher probability of occurrence than longer period winds.

The overturning problem can be broken into two parts. The first is the evaluation of the 2 second gust speed that will cause overturning and the second is the estimation of the probability that the critical overturning gust will occur from the required direction when the train is present and travelling at the appropriate speed. Reference 11 addresses this latter problem in some detail and some aspects of it are also discussed in Reference 3. Since this present paper is being written to emphasize the areodynamics of trains, it will only address the first point - the overturning phenomenon.

Overturning is complex, involving both mean and gust wind forces, track curvature, track superelevation, track vertical and horizontal irregularity, and suspension dynamics. Track irregularities and wind gusts can cause roll oscillations on the car suspension. The peak dynamic rolling moments so produced can add to the static moments caused by the steady wind and by the lateral forces due to cornering. In order to emphasize the aerodynamic effect, which is the main cause of overturning, the case of a rigid (no suspension deflection) train moving on a straight, horizontal track will be considered. This situation, depicted in Figure 9, produces a simple equation for the 2 second overturning wind speed based on the balance of the static aerodynamic overturning moment and the gravitational restoring moment about the lee rail. The equation is:

$$V_o(\Psi) = \left[2\ Wy/(\rho C_{RM}(\Psi) A_s h)\right]^{1/2} \quad \text{m/s} \qquad (24)$$

where $V_o(\Psi)$ is the yaw-angle-dependent, 2 second, overturning resultant speed (same as $V_r$ in Equation (3)), m/s

W is the weight of the car under consideration, N

y is one-half the rail gauge, m

$C_{RM}(\Psi)$ is the yaw dependent lee-rail aerodynamic rolling moment, Equation (15)

$A_s$ is the side area of the car under consideration, $m^2$

h is the height of the car's body, m

$\Psi$ is the wind-induced yaw angle, deg (Equation (2))

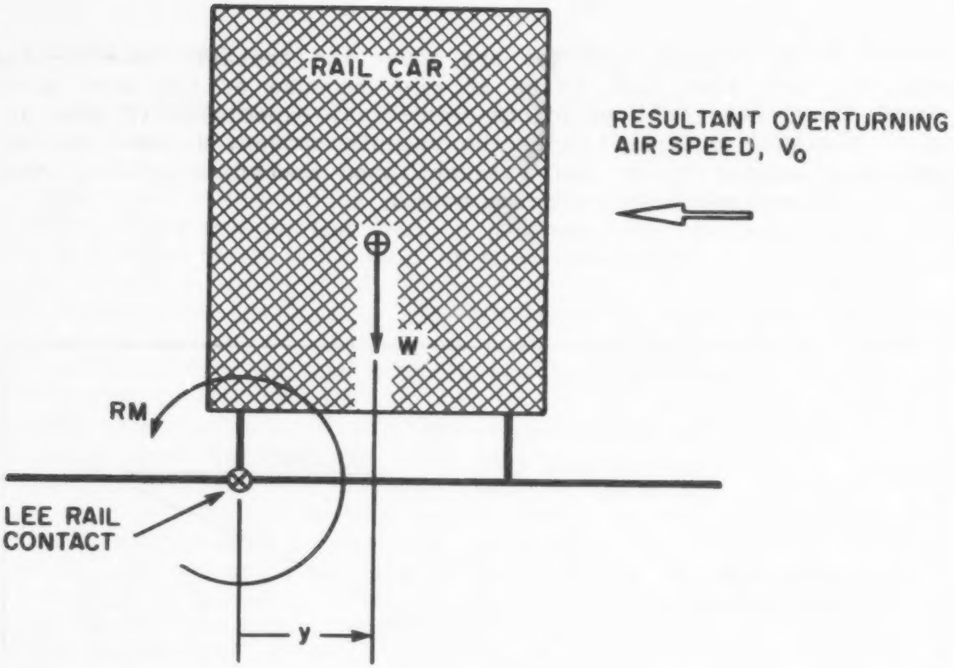


FIG. 9: MOMENT BALANCE FOR OVERTURNING

Thus, $V_o(\Psi)$ can be calculated for any yaw angle $\Psi$ for which the rolling moment is $C_{RM}(\Psi)$. Once $V_o(\Psi)$ has been determined, the value of **overturning wind speed** for that yaw angle can be obtained from Equation (3) by setting $V_o(\Psi) = V_r$ and solving for $V_w$. The simplest example is provided for a stopped train where $V=0$, $\Psi=\Phi$, $V_r=V_w=V_o$. In practice, this is often close to the governing design case. The worst case, that is the largest rolling moment, occurs for side winds where $\Psi=90°$ and $C_{RM}=C_{RM_m}$. In this case Equation (24) becomes:

$$V_o = V_w = \left[2\,Wy/\rho\,C_{RM_m}\,A_s\,h\right]^{1/2} \quad m/s \qquad (25)$$

As in the case of aerodynamic drag the behaviour is specified by a rolling density parameter, this time written as $Wy/(C_{RM_m}A_s h)$ N/m². A plot of overturning speed as a function of this density parameter is shown in Figure 10. Not surprisingly it has the same form as for the drag behaviour and, once again, low density vehicles have the greatest problems. Several typical rail vehicles, and a double-deck bus and a light shed structure that are both prone to wind overturning, are located on the curve. Rail cars with overturning speeds below 25 m/s are felt to be candidates for overturning occurrences, with the number of incidents expected to increase at lower densities. Since unrestrained single containers have been lost in the past, then double-stack containers will be more susceptible, and they will take the car over also. While transit vehicles are above the tentative overturning boundary, they are also felt to be at risk because of the more windy environment found near tall buildings in cities, expecially if they are running on elevated guideways. In the example chosen, locomotives and passenger cars appear to be safe, except when operating at very high speeds, as they are now just beginning to do.

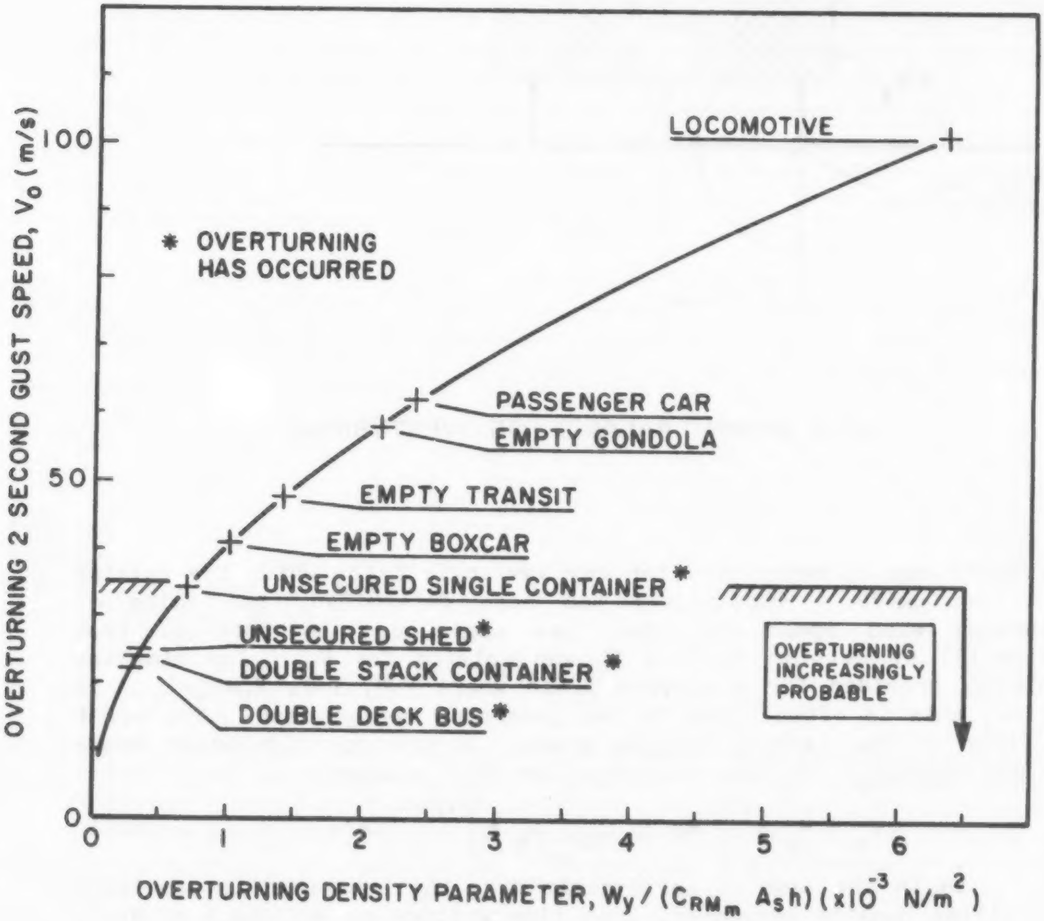


FIG. 10: UNIVERSAL OVERTURNING BEHAVIOUR

## 9.0 CLOSING REMARKS

The relevance of aerodynamics to rail vehicle energy consumption and wind-induced rail vehicle overturning have been examined. The aerodynamic drag density and the aerodynamic rolling density have been presented as parameters that govern the importance of aerodynamic influences on the train's performance. Aerodynamic effects grow in importance for small values of these parameters.

Achievable reductions in aerodynamic drag were shown to produce energy savings of significant magnitude, even though they were only a small fraction of the overall energy consumption. Whether any specific modification to old or new stock is warranted requires a careful economic analysis of the energy and productivity benefits. An indication of some of the levels of drag reduction possible, based on current model test results, was presented, but more work is necessary to identify and quantify the optimum aerodynamic changes. The optimum must satisfy both aerodynamic performance goals and operational requirements. The wind tunnel, supported by computational methods, track measurements, and performance analyses will be the most successful route to establish this optimum. Near-term improvements in wind tunnel simulation technology, especially relating to the ground/air interface and to our knowledge of train skin friction are needed to permit more accurate development of practical, lower-drag rolling stock designs.

An evaluation of the overturning behaviour of rail vehicles indicated that certain classes of rail cars may be susceptible to wind-induced overturning. Typically, the vehicles most at risk are those of high volume operating empty, having a low rolling density.

In closing, it would appear beneficial to examine more closely the drag and overturning behaviour of certain classes of low-speed freight vehicles, to retain an awareness of the possibility for overturning of elevated, light transit vehicles in the gusty city wind environment, and to maintain a continuing effort to improve the aerodynamic performance of high-speed passenger trains in order to counter the threat of steadily improving bus and aircraft efficiency.

## 10.0 ACKNOWLEDGEMENT

The author would like to thank Mr. William McLaren and Mr. Roy Nishizaki, both of Transport Canada, for the opportunity to present his thoughts on rail vehicle aerodynamics at the seminar on Rail Freight Research and Development, Montreal, June 1986. He would also like to thank Mr. Richard Cataldi of the Association of American Railroads for the helpful insight into rail operations and for the detailed information on rolling stock characteristics that helped to keep the paper on a realistic and practical level.

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## DISCUSSION ON
## PRESENTATION BY K.R. COOPER

G.W. ENGLISH (CIGGT): I was just wondering, on the double stack containers, whether the overturning moment was just for the container or is it that for a complete double stack car?

K.R. COOPER: That is for the complete car; that is, two containers roughly 19 ft. six high and 48 ft. wide on a well type car. So it is the car and empty containers. I used a tare weight of 32 tons.

G.W. ENGLISH: So an untied top container would be worse that that situation?

K.R. COOPER: I would expect so but I did not calculate that. We had examples some years ago. People shipping houses in half units and they were blowing off the trailers. They just sat there under their own weight so the solution was to tie the trailer to the house unit. But then they both went over, which is much worse, and the solution there was just not to drive very quickly on windy days or not drive at all. The only lucky thing was they always put the houses with the high side towards the centre of the road so they always blew off into the ditch. No one was ever hit by one of these; that is, no other traffic, but certainly the possibility of that kind of event can occur with rail vehicles if they are not anchored properly.

R.W. RADFORD (Chairman): There is an area of the CN system in Newfoundland where cars would blow off the track when the wind blew. There was a person employed for many years who could sniff the wind and would call up and advise them not to send the trains. People heeded what he said, as he turned out to be rather good at judging the wind.

One question I would like to ask is have you done any investigation of the tendency of an empty container to lift off the car, rather than just blow off in a crosswind? Is there likely to be a lift effect as well in some cases?

K.R. COOPER: We haven't looked at it for containers. We looked at the aerodynamic movement of things like sheds, and trailers, and other structures that are something like containers and generally, they roll over before they do anything. In some circumstances they might slide. They can do three things; they can slide, they can tip and they can lift up. You will find generally that they roll before anything else. That has been the situation and it may be, depending on the design, that some other event could occur; but the rolling results because the side force is usually larger than the lift force, so the lift force contributes to the rolling as does the side force; but the side force does not contribute to the lifting. You have more things against you for overturning than for either sliding or lifting.

R.W. RADFORD (Chairman): Any more questions?

R.W. SMITH (Queen's University): I saw right at the bottom of your slide, a double-decker bus; is that right - an English double-decker bus?

K.R. COOPER: That was put in just as an example.

R.W. SMITH: They run regularly on motorways now in the UK. Have there been cases where they have been blown over sideways?

K.R. COOPER: I put that in there because, when I was in England a few years ago, somebody said that this bus is blowing over on the bridge and can you calculate the speed at which it would do that? It came out that it would be about 50 miles an hour, which is roughly what the wind velocity was; so they all felt happy that the wind had caused it. So the bus definitely goes over quite easily. The containers are at the speed where certainly, at some times of the year in the windier parts of both Canada and the States, that can happen. But the double-decker bus, because of its height, has a high rolling moment and it is still quite a low density vehicle. It is mainly empty, so its tendency to turn over is considerable. Its weight or mass, which prevents it from overturning, is not too big and the moment that is trying to turn it over is pretty big, so it rolls over quite easily. I think that they have now been excluded from the motorways in Britain because there have been a few of these incidents.

D.N. FERRENCE (UTDC): It occurs to me that this is a sort of static condition that you have been outlining here and of course there are many circumstances in which you can have wind tunnel effects and very much higher winds than you would normally encounter out in the open, and that in fact, this characteristic might be a lot more important than is apparent even from your graph.

K.R. COOPER: That is true; there are lots of reasons to make it more important. First of all, wind statistics are usually reported in mean hourly speed. The gust that blows the vehicle over is about a two-second gust. It takes a very short time to blow a vehicle over; it's a static instability so as soon as it starts to move, the restoring moment due to its weight diminishes. The more it rolls, the less the restoring moment and the more it rolls, so it is like a marble on a hill. You push it off and it is gone. So the event happens very quickly and requires only a short period gust. Thus, if you get a 60 mile-an-hour wind, as the overturning wind, that really means the mean hourly wind is more like 40 miles an hour, which is getting quite low. Almost any front passage has wind that may gust at 45 miles an hour and that happens quite a few times in our summers. When you get down to the range of 50 mile-an-hour blow-over speed, you are getting in the realm of potential of frequently recurring problems with any sensitive vehicle. So the bus is definitely there, and the transit vehicles and the double-stack empty containers may be close to there. Again, local conditions can enhance the winds. Certain parts of the country are windier than other parts. Local terrain effects like hills or elevated sections of track will cause wind flow acceleration, so one can look at statistics of wind in various parts of the country and make some estimates about where bad places are. You can even perhaps make observations along the line from local vegetation and other things to determine the more dangerous places. The whole problem is a statistical one. You can calculate the overturning speed but to determine the likelihood of occurrence of that at any point on the track is quite a different problem. If you want to put in the effort to find a solution, it is going to cost a few dollars so it might be a lot easier just to carry some ballast for example, rather than tackle the whole problem. You have to acknowledge that aerodynamics do influence rail vehicles in several ways.

F.B. BLADER (Consultant): I wanted to make the point that the overturning of a train is a good deal more complicated than is currently being suggested. Aerodynamics is indeed an important aspect of it but it comes in as a combination of a host of other things which you might not find on English double-decker buses or other strange vehicles.

K.R. COOPER: We have looked at other things; for example, the dynamics of the vehicle suspension and the wind gust. Also, the rails are not perfectly level. All these things excite roll motions of the vehicles so that you have this sort of an inertial effect adding to the aerodynamics effect. There are also the cornering and super-elevation effects. We have looked at some of these in our analyses. I just presented a very simple thing because if gets the idea across but in fact, there are things that make it worse. If a car can tilt, if it can oscillate, if the track is tilted depending which way, if it is going around a curve too quickly or not, then all these add additional terms which usually make the thing go over more readily - not the other way around.

W. SERGEANT (CANAC): You raised a point about the significance of a train normally on a surface so that the effects of the wind are on the top of a surface. I wonder what the effect is if it's on a bridge or on a high viaduct where air can pass underneath as well as over the top. What is the influence of that on the overturning of a vehicle?

K.R. COOPER: It is usually worse, because the flow is accelerated. If a vehicle happens to be just there, the overturning force is higher. In fact, that first bus case I mentioned occurred on a bridge. The bridge behaves in a way like a bump on the ground that causes a flow acceleration which worsens the situation.

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# FRAME BRACING FOR 3-PIECE CAST STEEL FREIGHT TRUCKS THE ECONOMICAL "RADIAL" TECHNOLOGY

J.W.Horwat
Project Engineer
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## ABSTRACT

The Frame-Braced Freight Truck program was begun in 1980 as an integral research program and expanded to a research, design, build and test program in 1981 under the sponsorship of the Transportation Development Centre and Ontario Ministries of Transportation and Communication and Northern Affairs. The program resulted in a simple design of a new truck or retrofit parts which when added to a conventional three-piece freight truck improves the dynamic stability and curving ability of the truck, increasing operating speed capability and reducing wheel, especially flange, wear. Research results and test results are presented graphically showing their relationship. In addition, the market and the sales to date are discussed, as is also the favourable cost/benefit analysis.

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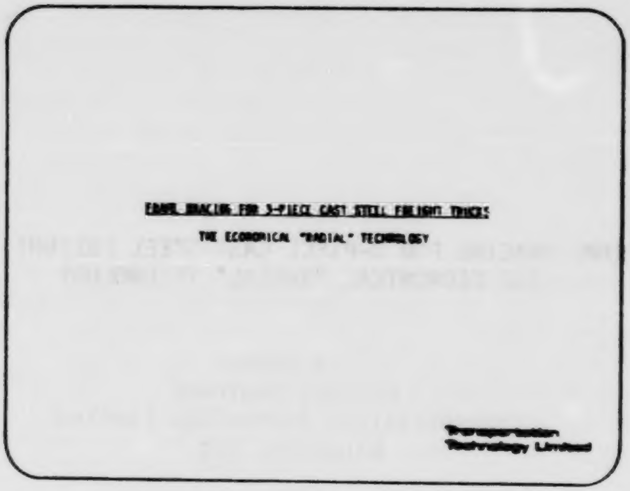

FRAME BRACING FOR 3-PIECE CAST STEEL FREIGHT TRUCKS

THE ECONOMICAL "RADIAL" TECHNOLOGY

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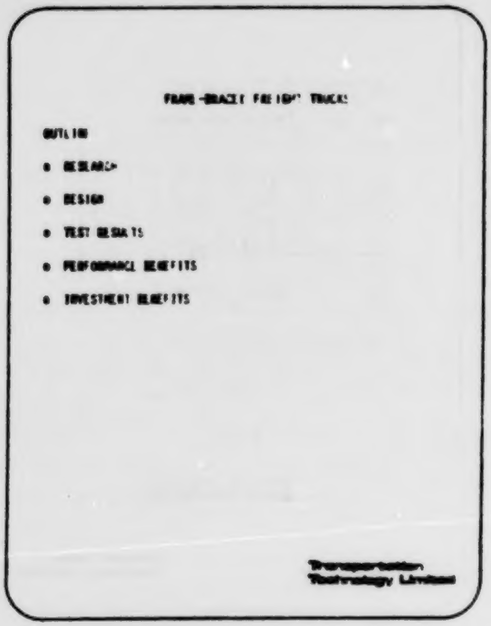
This presentation describes a program carried out by, originally, UTDC R&D Ltd., one of the UTDC Group of companies. Since then, UTDC R&D Ltd. has become Transportation Technology Limited.

The subject of that program was a concept of modifying the standard three-piece freight truck to improve its performance; increasing the critical speed, and reducing wheel and rail wear.

The concept is called "Frame Bracing" and classified as the "Economical Radial Technology".



FRAME-BRACED FREIGHT TRUCK

OUTLINE

- RESEARCH
- DESIGN
- TEST RESULTS
- PERFORMANCE BENEFITS
- INVESTMENT BENEFITS

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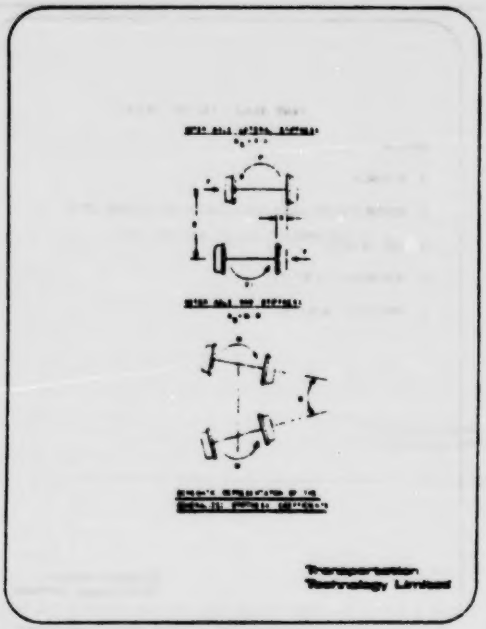
The presentation comprises five parts. I will begin by describing the RESEARCH that was carried out with the result which encouraged us to carry on. I will then go into the DESIGN aspects, describing how the truck is modified and what the parts do. Testing of this concept was a part of the program and has been carried on at various facilities, consequently the TEST RESULTS will be outlined. Because the frame-braced truck is intended to be a marketable product, and it is, it must have some benefits. For those customers' technical people, there are PERFORMANCE BENEFITS. For those financial, there are INVESTMENT BENEFITS. Both will be covered.



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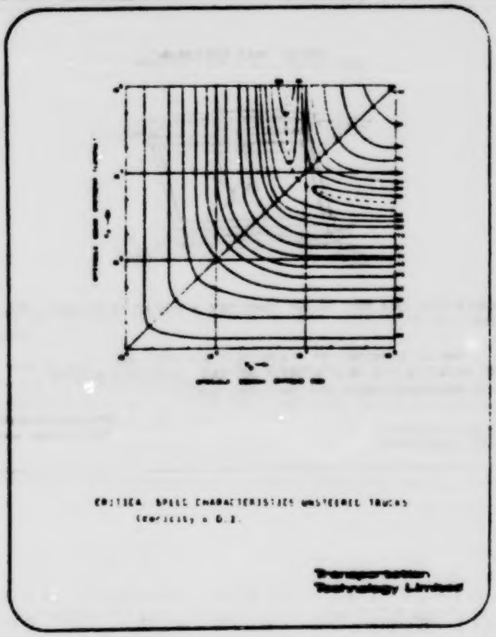
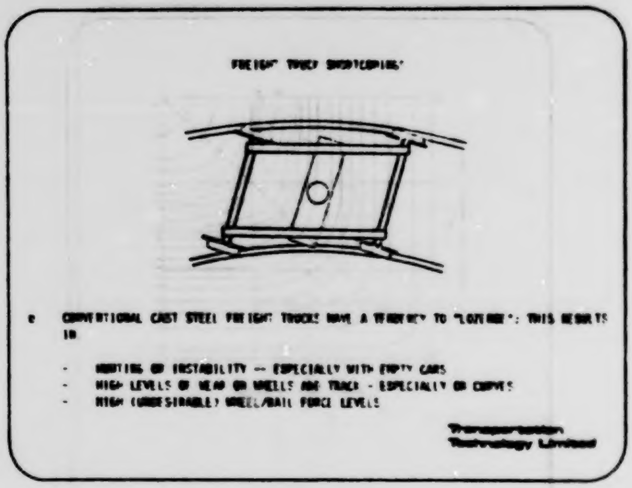
In the past, and the practice continues, rail car analyses have been performed using a model wherein the wheelsets were connected by a "black box" that had attributes quantified in terms of the truck interaxle shear stiffness $k_s$ where $k_s$ was the force required to displace in a parallel fashion the two wheelsets, divided by the displacement. As well, the truck also possessed an attribute known as the bending stiffness $k_b$, the ratio of the moment required to anti-parallel the wheelsets and the angle of anti-parallel displacement. The acceptability of this form of parametric analysis really states that how the designer achieves his desired values of $k_s$ and $k_b$ is secondary to the actual achievement.



By varying the shear and bending stiffnesses on a vehicle, a family of curves can be produced showing vehicle critical speed $V_{crit}$ as shown here, wheelset Angle of Attack, Tread Wear Index and Flange Wear Index. This plot of the $V_{crit}$ family of curves shows a symmetry about a roughly 45 degree line. In essence, for $V_{crit}$ at least, one can be on the curve on either side of the line of symmetry and the performance would be the same.

This plot of $V_{crit}$ versus $k_s$ and $k_b$ is the result of a 17 degree degree of freedom linear mathematical model, empty vehicle, full creep and a wheel conicity of 0.2 or approaching worn wheel condition.



FREIGHT TRUCK SHORTCOMINGS

- CONVENTIONAL CAST STEEL FREIGHT TRUCKS HAVE A TENDENCY TO "LOZENGE": THIS RESULTS IN
  - HUNTING OR INSTABILITY -- ESPECIALLY WITH EMPTY CARS
  - HIGH LEVELS OF WEAR ON WHEELS AND TRACK - ESPECIALLY ON CURVES
  - HIGH (UNDESIRABLE) WHEEL/RAIL FORCE LEVELS

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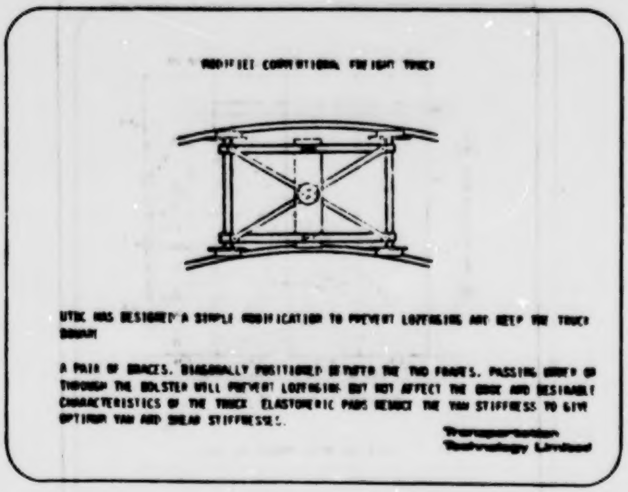
The current three-piece cast steel freight truck is basically a good design albeit some 50 years old. It certainly is rugged, easy to maintain, relatively inexpensive and under normal circumstances provides good wheel load equalization. Conversely, the truck has its faults; it is very heavy, permits truck lozenging and by design restricts axle anti-paralleling or steering. Hence it is easily concluded that bending stiffness $k_b$ is for too large while shear stiffness $k_s$ appears to be far too small. At a $k_s$ of $10^5$ N/m and a $k_b$ of $10^8$ Nm/rad, it can be seen by looking back at the previous plot that a low critical speed can be expected, i.e., hunting occurs at a speed below that which is desirable. We already know wheel wear is a problem.



MODIFIED CONVENTIONAL FREIGHT TRUCK

UTDC HAS DESIGNED A SIMPLE MODIFICATION TO PREVENT LOZENGING AND KEEP THE TRUCK SQUARE

A PAIR OF BRACES, DIAGONALLY POSITIONED BETWEEN THE TWO FRAMES, PASSING UNDER OR THROUGH THE BOLSTER WILL PREVENT LOZENGING BUT NOT AFFECT THE GOOD AND DESIRABLE CHARACTERISTICS OF THE TRUCK. ELASTOMERIC PADS REDUCE THE YAW STIFFNESS TO GIVE OPTIMUM YAW AND SHEAR STIFFNESSES.

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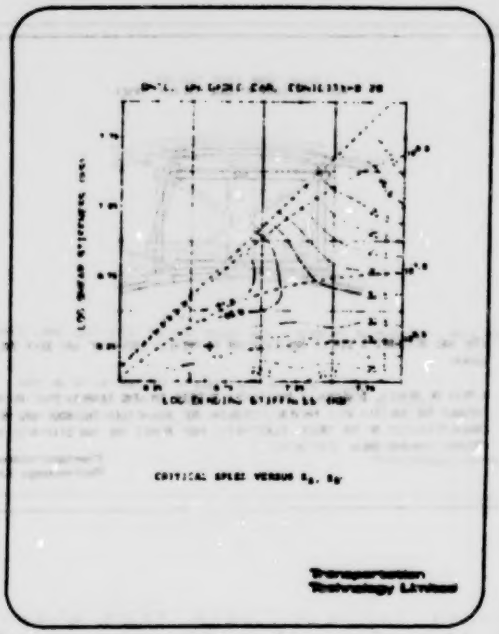
It seemed logical therefore that to increase the shear stiffness, either the wheelsets needed to be linked such as on those "radial" trucks or the sideframes could be locked together such as is common on transit trucks. TTL elected for reasons very obvious, to "brace" the sideframes. The next task was to reduce the bending stiffness to permit natural steering. Some resiliency was required at the sideframe/axle connection.



CRITICAL SPEED VERSUS $K_s$, $K_b$

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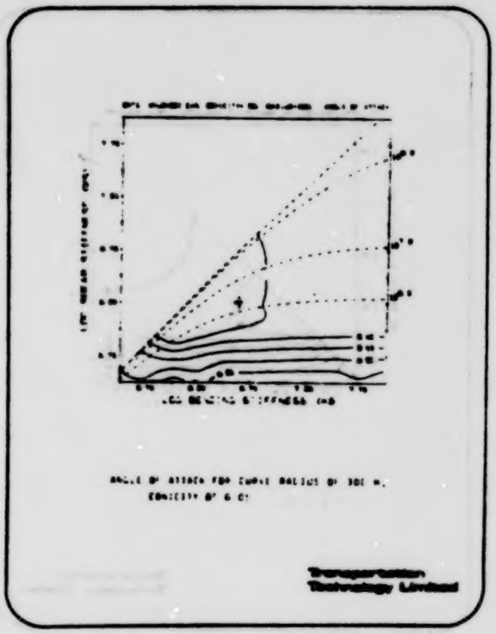
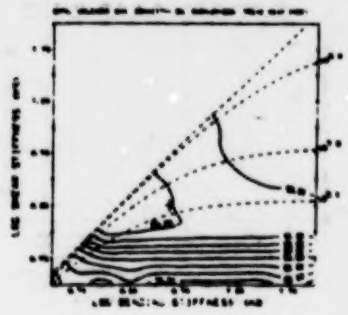
With the introduction of braces between the sideframes and resilient elements at the pedestals, a 29 degree of freedom model was created to describe the vehicle, and the individual relationships calculated to produce $k_s$ and $k_b$. From this was produced the family of curves of critical speed versus $k_s$ and $k_b$. The inter sideframe bracing restricts the results to those curves lying below $k_s = k_b$, 45 degree line, but from classical studies, the curves would be somewhat symmetrical around the $k_s = k_b$ plane, where the results of some other arrangement of axle control would reside. At this point, the availability of actual hardware was investigated. The resilient elements at the sideframe pedestal were already available in discrete values of shear stiffness. The same supplier produced a resilient brace element which closed the loop. The elements produced a $k_s$ of $10^{6.25}$ ($1.779 \times 10^6$) N/m and a $k_b$ of $10^{6.64}$ ($4.365 \times 10^6$) Nm/rad as shown by the cross on the plot. This yielded a calculated critical speed with "worn" wheels of near 27.5 m/s or 61.5 mph.

It is generally accepted in the industry that the conventional 100 ton truck exhibits shear and bending stiffnesses near $10^5$ (100,000) N/m and $10^8$ (100,000,000) Nm/rad. This value would produce a critical speed generally less than 22.5 m/s or less than 50.3 mph, which I believe few people in the industry would dispute.



But Frame Bracing is intended to decrease wheel wear as well as increase hunting speed. One indicator is this plot; the results of a parametric analysis of quasi-static non-linear curving. In this case, we're looking at the results of analysis using the same vehicle as in the $V_{crit}$ plot but with a new wheel and on a 300 m (984 ft, 5.83 degree) curve. Based on our chosen values of $k_s$ and $k_b$, the frame-braced truck should achieve an angle of attack of slightly less than 0.35 degree. Also based on the accepted values of $k_s$ and $k_b$ for the conventional truck, it would achieve an angle of attack in excess of 0.55 degree. Frame bracing provides an improvement of near 1.57 to 1.



TREAD WEAR INDEX, 300 m CURVE RADIUS, 0.05 CONICITY

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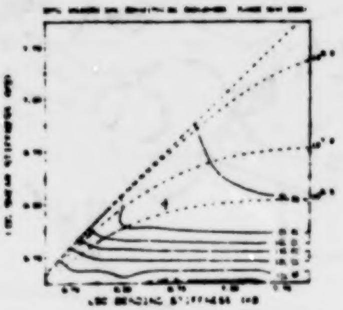
As angle of attack is an indicator of good curving, when coupled with wheel tread forces, it becomes a Tread Wear Index (TWI). Although TWI will not predict actual tread wear, it is somewhat like the automobile fuel consumption rating in that it allows comparison between cars, trucks, steering types, etc. In this case, on a 300 m curve with a wheel tread cone angle of 0.05 (1:20) or new wheel, the TWI for a conventional truck ($k_s = 10^5$, $k_s = 10^8$) is in excess of 70 Nm/m while for the Frame Braced Truck ($k_s = 10^{6.24}$, $k_b = 10^{6.64}$) TWI is less than 35 Nm/m for a 2:1 improvement. It becomes obvious then that considering the angle of attack improvement of 1.57:1, that tread lateral and longitudinal forces are decreased as well. Since the wheel tread interacts with the rail head, a comparable improvement in rail wear would be expected.



FLANGE WEAR INDEX, 300 M CURVE RADIUS,
0.05 CONICITY

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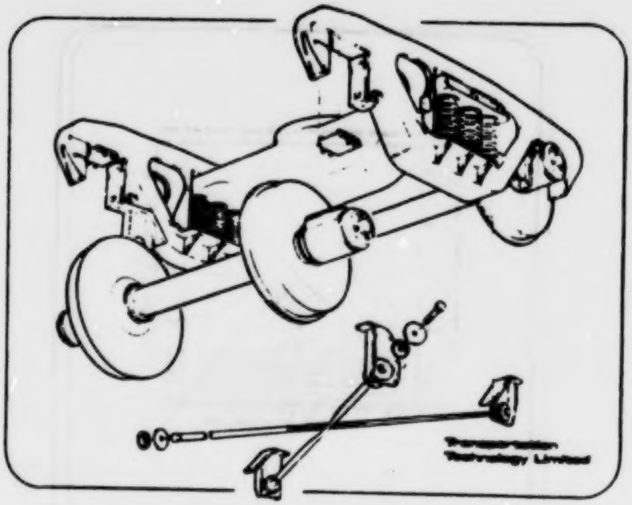
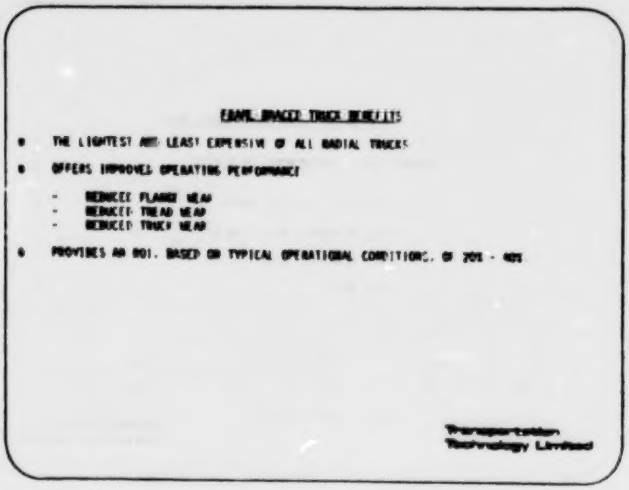
As with TWI, the Flange Wear Index (FWI) can also be evaluated. This incorporates angle of attack and flange forces. Of course, flange free running creates no forces and hence no wear. In this case, on a 300 m curve with a conicity of 0.05, the FWI for a conventional truck ($k_s = 10^5, k_b = 10^8$) on this vehicle is near 140 Nm/m while for the frame braced truck ($k_s = 10^{6.29}$ $k_b = 20^{6.64}$ marked with a cross), the FWI shows slightly less than 90 Nm/m for an improvement of 1.56.

What all of these analytical results means is that there is a high probability of achieving practical results reflecting the analytical trends.



The actual hardware looks like this. We have the conventional three-piece freight truck - sideframe, bolster, wheelsets, adapters, springs. The frame braced truck features two tubular rods crossed in the middle and attached through resilient centre-bonded bushings to brackets precisely located and welded to a base plate and to the sideframe. This arrangement increases the shear stiffness of the wheelsets. Inserted between the bearing adaptors and the sideframe pedestals are resilient rubber/steel sandwich pads. The addition of these pads reduces the truck shear stiffness slightly but reduces the bending stiffness far more significantly. In addition, the bearing adaptor longitudinal faces are ground to provide 5 mm fore and aft clearance for self-steering. All of this hardware adds only 230 kg to the mass of a car.



**FRAME BRACED TRUCK BENEFITS**

- THE LIGHTEST AND LEAST EXPENSIVE OF ALL RADIAL TRUCKS
- OFFERS IMPROVED OPERATING PERFORMANCE
  - REDUCED FLANGE WEAR
  - REDUCED TREAD WEAR
  - REDUCED TRUCK WEAR
- PROVIDES AN ROI, BASED ON TYPICAL OPERATIONAL CONDITIONS, OF 20% - 40%

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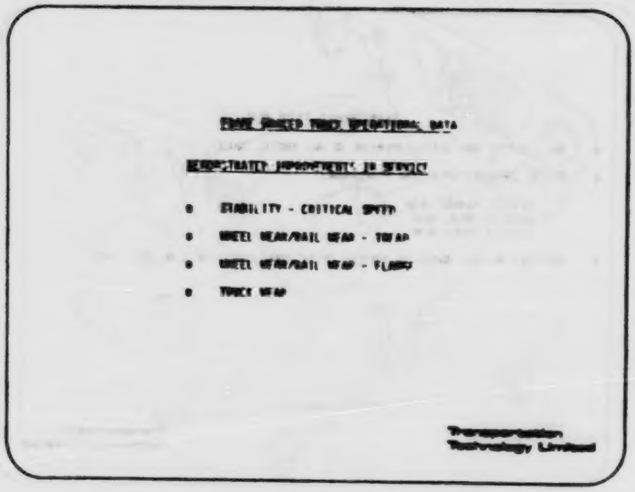
As a marketable product, there has to be some benefits to the customer both tangible and intangible. As just mentioned, the mass of a car is increased only 230 kg, therefore based on best information, it is the lightest of all of the radial trucks. At our current price of US $2500 per carset, it is the least expensive of all the radial trucks by some 30-50%. As we have seen by analysis and will see from testing, the frame-braced truck offers improved operating performance in reduced tread and flange wear and truck wear. It must be stated now that no evidence of reduced truck wear is available. Our first truck teardown is scheduled for September/October 1986 after 200,000 miles of travel. For this marketable product, we have had to determine a return on investment (ROI) for various potential users. I'll discuss that last.



**FRAME BRACED TRUCK OPERATIONAL DATA**

**DEMONSTRATED IMPROVEMENTS IN SERVICE**

- STABILITY - CRITICAL SPEED
- WHEEL WEAR/RAIL WEAR - TREAD
- WHEEL WEAR/RAIL WEAR - FLANGE
- TRUCK WEAR

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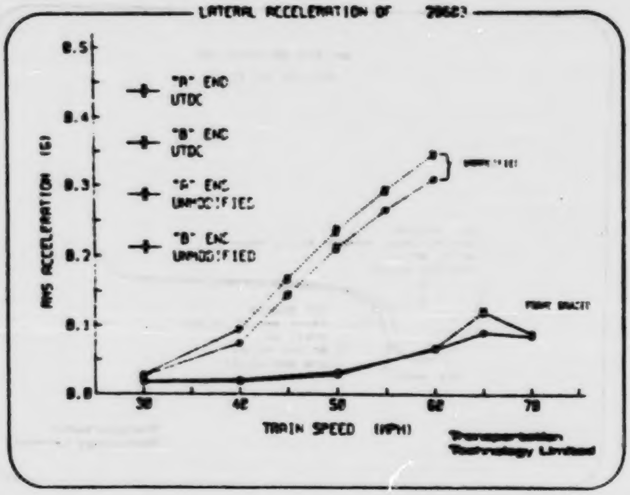
I have described in general the technical and economic benefits of the truck. Specifically, the following pages will show those benefits occurring from actual test. Those benefits show up in an increase in critical speed and a decrease in wheel wear. As mentioned before, no hard truck wear data is yet available.



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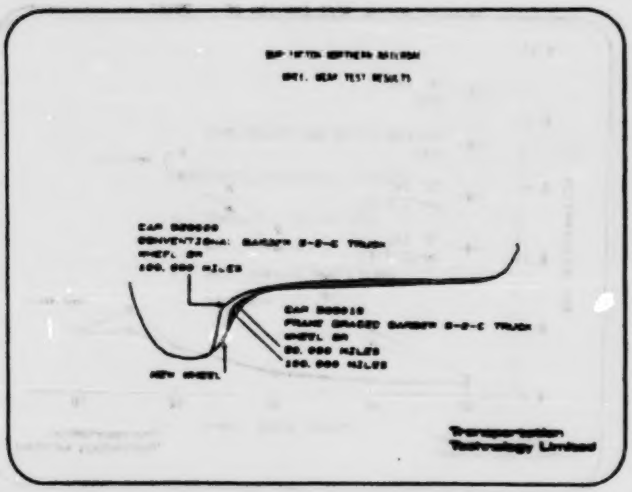
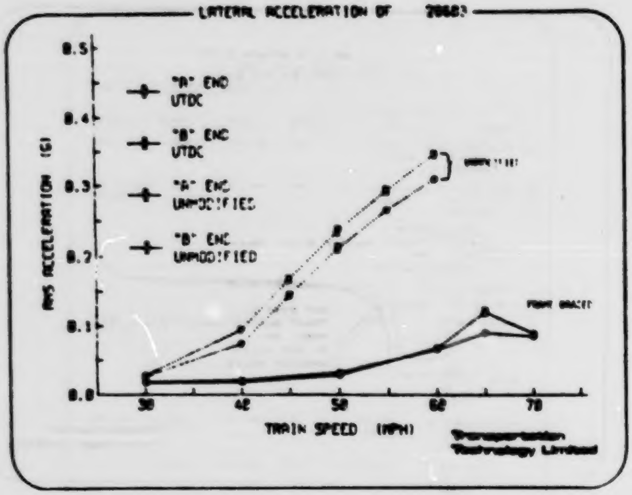
These are the plotted results of a test carried out on a short ore car. The test was a classic comparison test where the car was pulled from service, tested, disassembled, frame-bracing installed and reassembled and tested. The only other difference was that the conventional trucks were equipped with C-PEP while the frame-braced truck was not. In terms of lateral accelerations of the carbody, the frame-braced trucks produced rms acceleration levels at 70 mph less than half of the conventional at 60 mph. The conventional car at 60 mph was sufficiently violent that the train crew would not attempt 70 mph. In another way, the frame-braced truck reduced carbody accelerations at 70 mph to that of the conventional truck at just over 40 mph.



Probably the largest tangible benefit of frame-bracing is the reduction of wheel wear. This slide shows three profiles of one wheel on a Frame-Braced truck equipped car at 50,000 miles, 100,000 miles and new.

It also shows two profiles of a wheel on a non-frame-braced equipped car at new and 100,000 miles. There has been so little wear of the frame-braced wheel that the 50,000 mile and 100,000 mile trace virtually coincide while there is a large difference between them and the conventional truck wheel, and in keeping with the industry findings, the largest difference is in the flange area. The results of this and 23 others have shown an overall average wear advantage of more than 2:1.



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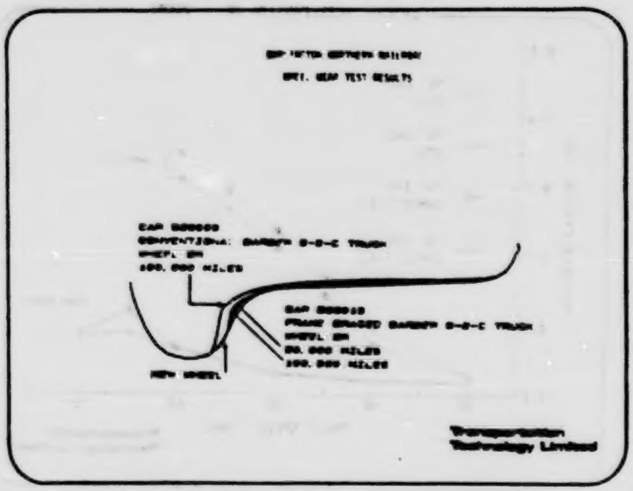

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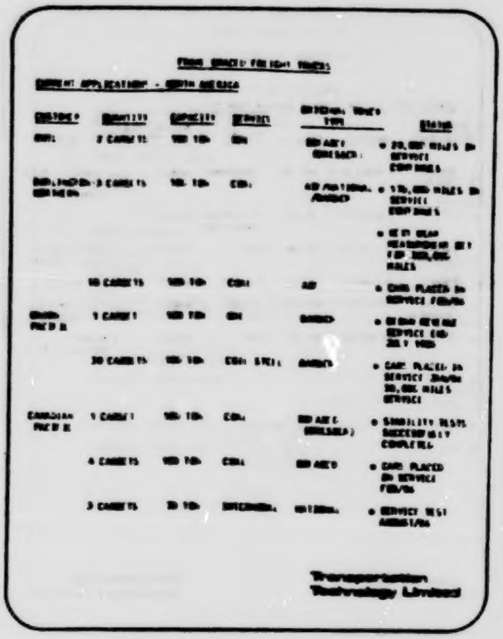
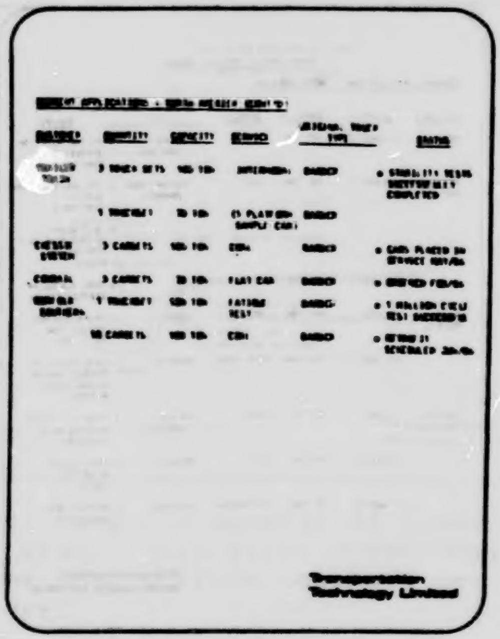


Good marketable products need customers who can derive benefits from the marketable product. The frame-braced truck is no exception. There are 54 carsets running in revenue service, or ready for test and service at these railroad facilities.

Exceptions/amendments to the status are as follows:

- the 10 BN cars are scheduled for fuel savings tests in the summer and are not running;
- the 1 carset at UP is not running.

It can be seen that there is a general wide acceptance of the Frame-Braced truck idea.



Notable exceptions on this slide are:

- o the braces have been removed from the TTX sample car for load clearance tests.
- o The Chessie cars are just going into service having experienced some internal Chessie delays.
- o Conrail have ordered an additional 5 carsets.

Currently three private car owners in addition to Trailer Train have shown a definite interest.

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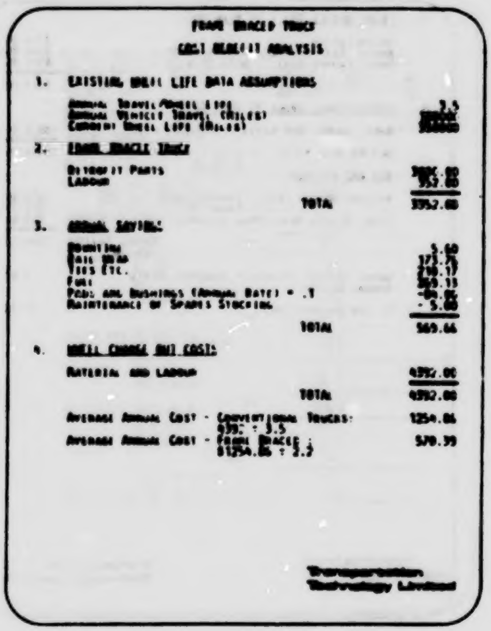

FRAME BRACED TRUCK

COST BENEFIT ANALYSIS

| | | |
|---|---|---|
| 1. | EXISTING WHEEL LIFE DATA ASSUMPTIONS | |
| | Annual Travel/Wheel Life | 3.5 |
| | Annual Vehicle Travel (Miles) | 100000 |
| | Current Wheel Life (Miles) | 350000 |
| 2. | FRAME BRACED TRUCK | |
| | Retrofit Parts | 3000.00 |
| | Labour | 352.00 |
| | TOTAL | 3352.00 |
| 3. | ANNUAL SAVINGS | |
| | [illegible] | 5.60 |
| | Rail Wear | [illegible] |
| | Ties Etc. | [illegible] |
| | Fuel | [illegible] |
| | Pads and Bushings (Annual Rate) = .1 | [illegible] |
| | Maintenance of Spares Stocking | - 5.00 |
| | TOTAL | 569.66 |
| 4. | WHEEL CHANGE OUT COSTS | |
| | Material and Labour | 4392.00 |
| | TOTAL | 4392.00 |
| | Average Annual Cost - Conventional Trucks: $4392 ÷ 3.5 | 1254.86 |
| | Average Annual Cost - Frame Braced: $1254.86 ÷ 2.2 | 570.39 |

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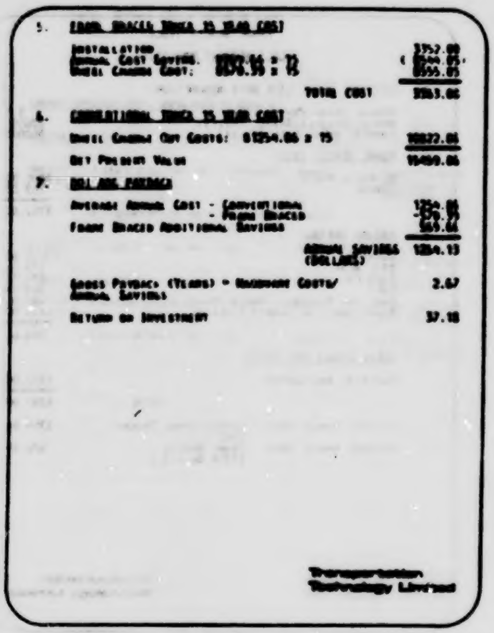
We've covered the technical benefits, tread wear, flange wear, but to the man who signs the cheques, he needs to know what the benefits are in dollars. This analysis has been formulated from the CIGGT Report 82-3, "Rail Wear Economic Analysis for Type II Trucks" based on a price of C$3000 per carset (actual price is US $2500) and a railroad whose cars travel 100,000 miles per year with an average wheel life of 350,000 miles. In annual savings from elements other than direct wheel wear, we achieve $569.66. The wheel changeout costs have been derived from 1983 AAR costs and the wheel wear ratio, conventional to Frame-Braced, is 2.2.



5. FRAME BRACED TRUCK 15 YEAR COST

INSTALLATION [illegible]
ANNUAL COST SAVINGS: [illegible] x 15 ( [illegible] )
WHEEL CHANGE COST: [illegible] x 15 [illegible]

TOTAL COST [illegible]

6. CONVENTIONAL TRUCK 15 YEAR COST

WHEEL CHANGE OUT COSTS: $1254.86 x 15 [illegible]

NET PRESENT VALUE [illegible]

7. ROI AND PAYBACK

AVERAGE ANNUAL COST - CONVENTIONAL 1254.86
- FRAME BRACED -570.39
FRAME BRACED ADDITIONAL SAVINGS 569.66

ANNUAL SAVINGS (DOLLARS) 1254.13

GROSS PAYBACK (YEARS) = HARDWARE COSTS/ ANNUAL SAVINGS 2.67

RETURN ON INVESTMENT 37.1%

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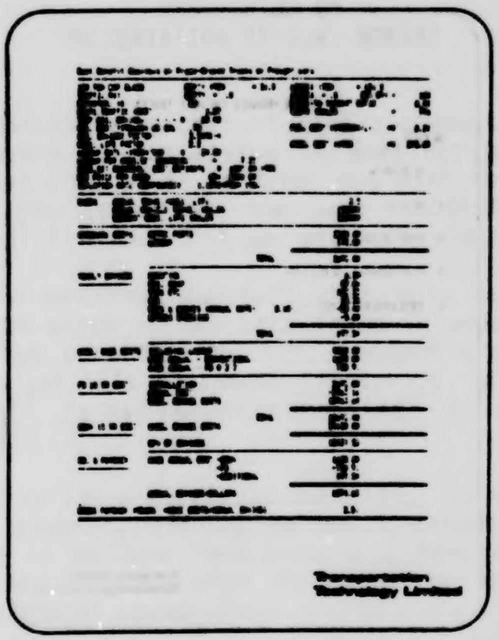
Running down to Item 7, the Summary, the Annual Cost for a conventionally equipped car is $1254.86 while for a Frame-Braced equipped car is only $570.39. Accounting for the non-wheel wear related savings of $569.66, finally yields an annual savings of $1254.13. Based on non-discounted funding, the gross payback would take less than three years for a non-discounted ROI of 37.1%. Accounting for the cost of money would increase the payback period slightly and decrease the ROI slightly.



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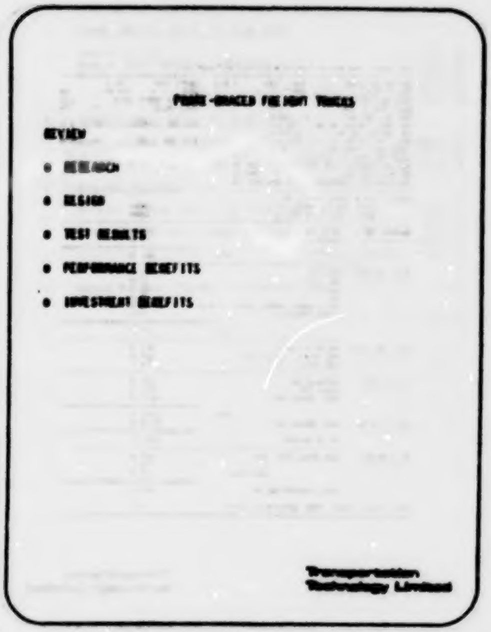
This ROI analysis was carried out for a railroad whose cars achieve the some 100,000 miles per year but whose wheels only last 250,000 miles. At the current cost of US $2500, non-AAR wheel changeout costs, and slightly different trackage, the gross payback period would be 2.51 years and, although not calculated, the ROI would exceed 37 percent.

It becomes clear that high mileage cars benefit most from Frame Bracing.



FRAME-BRACED FREIGHT TRUCKS

REVIEW

- RESEARCH
- DESIGN
- TEST RESULTS
- PERFORMANCE BENEFITS
- INVESTMENT BENEFITS

Transportation
Technology Limited

In summary then, I've discussed the Research that went into the program, essentially the parametric mathematical analyses for stability, angle of attack and wheel wear, the results showing that increasing shear stiffness $k_s$ and decreasing bending stiffness $k_b$ to just practical levels produced a better performing three piece freight truck.

I also discussed the Design of the truck showing that the resiliently-mounted crossed braces were responsible for the increase in $k_s$ while the adaptor/sideframe pads reduced $k_b$ and still maintained axle yaw control. Both of these elements had a negligible effect on the good qualities (ruggedness, wheel load equalization, etc.) of the basic truck.

I discussed the Test Results and Performance Benefits showing the apparent increase in critical speed of one car and the reduced wheel wear from another car, the simplicity of the design and the low weight added to the car. I also showed a list of the users and the status of that use.

Finally, I showed cost/benefit analyses for two real cases of customer cars, illustrating quite clearly that high mileage heavy haul cars can produce a reasonably quick payback on the initial investment of Frame Braced trucks.

I believe I can say that the potential for this product is great and TDC, MTC, MNA, and UTDC made excellent investments in the program.

## DISCUSSION ON
## PRESENTATION BY J.W. HORWAT

**P. MARCOTTE (CN Technical Research):** I have a comment and a question. The comment is with respect to you saying it does not matter how you get $k_s$ and $k_b$. I agree that some of it is true, but with the truck configuration that you have now, you cannot get the same combination of $k_s$ and $k_b$ as some of the other radial trucks that you are referring to.

The question I have concerns the fact that this is a retrofit and you actually have to make welds on the side frame in areas in which I believe welding is not really permitted by AAR standard practices. How do you ensure that when you put this equipment in service, it will last as long as it would have lasted if it had not been modified? I understand that this is a difficult question.

**J.W. HORWAT:** No, it is not a difficult question. In the first case you are right. There are some $k_s$ and $k_b$ values I cannot achieve. But then again, I don't have to achieve them because I have all of those elements that other people are getting with different $k_s$ and $k_b$ values. I am still on that same critical speed line.

The part about not being able to weld in that area is not true. In fact, if you look at the original specifications for new trucks, you are allowed to weld in that area to make that new truck a good truck or to make that new side frame a good side frame. In the specifications, both in the field manual and in M210, welding is permitted there as long as it is not for reconditioning purposes. That is the only condition and we agree with that. If you have a hole punched through there or a crack, you should not be able to weld in that tension member area, but as long as you are starting with a new truck, there is nothing written that says you cannot do it.

**P. MARCOTTE:** On your first point, I believe that if you have, like the combinations of $k_s$ and $k_b$, if you have a curve, a truck combination that is very flexible in yaw and very stiff in the lateral plane which you cannot do, you can demonstrate that they can go to very high degrees of curvature and remain radial which I don't believe will happen with that combination. On the second one, I think that by introducing welding on cast material, you obviously change the metallurgical aspect of it and I believe you will affect the limit of the fatigue loading to which it can be subjected. I would not have any data on that but I understood your point.

**J.W. HORWAT:** I can agree with you in one respect, although when you cite that combination you will have, and I will use the terms yokes (because that happens to be one of them out there), two yokes hooked together at the centre and the axles moving together. If I do an analysis using $k_s$ and $k_b$ alone, without taking into account what the mechanism is, I will find that there is a different angle of attack on the leading axle than there is on the trailing axle. This tells me that either the leading axle is going to try to pull the trailing axle in the same way, or the trailing axle is going to try to pull the leading axle back. Neither one of them is going to steer perfectly, even if they are hooked up with a very very high shear stiffness. Using the system I have, I essentially let the axles go. I said it is not worth hooking those two axles together. Consequently, neither one of us gets ideal angles, but because the cars go both ways, I am going to get the same angles over the years.

As to the welding, I guess the truth will come out 20 or 30 years from now, or whenever we have a failure. The analyses we have had done by various people, and we have also had a fatigue test done on that system at Norfolk Southern Corporation, showed that nothing went bad after a million cycles. It is not three million; it is not five million; it is not 30 years worth, I agree, but nothing bothered that whole system after a million cycles and that was a million cycles of something like 57% overload vertically, so we have done some testing. They are satisfied to the point where they are going to install it. So, as I say, in 20 years, we can talk again, but I don't see any problem. The specifications say that for re-conditioning purposes, I can't do it. If I start with an integral good side frame, nothing is stopping me at all, nothing in the rules is stopping me.

**F.B. BLADER (Consultant):** Can I raise a mild objection to the use of the wear index which you are using. It is not a reasonable wear index in the sense that it only takes account of lateral forces and lateral effects. Now wear takes place in the tread contact zone because of longitudinal and lateral forces, and the longitudinal forces on the trailing wheelset are often larger than the lateral ones, so when one is talking about a wear index, it is rather important that one should really take longitudinal creepage as well as lateral creepage into account.

**J.W. HORWAT:** If we are talking about light vehicles, you can compare one to the other without putting an absolute against it, and I would never put an absolute against tread wear index and flange wear index; but I do use it for comparison based on that $k_s$ and $k_b$ relationship.

**F.B. BLADER:** I am not comparing treads and flats.

**J.W. HORWAT:** No. I think I understand what you are saying. You are saying that I have not taken into account longitudinal forces. Agreed, I have not. If I did that, then I could get a tread wear index without caring about what the radius of the curve is because i would get it on straight track as well.

**F.B. BLADER:** Well you could correlate it to the actual amount of wear.

**J.W. HORWAT:** Certainly. The only reason for the tread wear index and flange wear index that I have shown, and that has been shown hundreds of times in papers here and there, is essentially to compare two vehicles based on $k_s$ and $k_b$ without taking into account anything else. To put those two vehicles on that same curve, we are using the same parameters for both. We are using lateral forces only and not longitudinal, so we are not comparing one longitudinal and one lateral, nor are we applying the tread wear index itself against actual fact, because I don't know what the actual fact is; but I do know that I can compare two vehicles based on what I have on a piece of paper and that is all I use it for. I would never tell you that the tread wear is going to last five times longer than something else, without doing that something else as well.

G.R. CATALDI (AAR): This is not really a question, but in the States, there is quite a bit of interest in wheel/rail lubrication and that is certainly an alternative, perhaps a supplement, to these kinds of trucks. It allows you to not only reduce wear on your high mileage vehicles but on all vehicles at least on those routes where you are lubricating, and of course also reduce rail wear and you don't have to be converting every car on a train. The lubricating device may be installed either on a locomotive or a high rail vehicle. Benefits appear quickly, as soon as your first units are equipped and operational. In some tests in the States, both wheel and rail wear in some territories that had high wear have dropped measurably very quickly, so it is just another area, an alternative research area to this.

J.W. HORWAT: Can I make two comments about that. Firstly, rail lubrication is not free; it costs a lot of money to put in rail lubricators and secondly, the rail lubricant gets flung all over. I don't know what it does to brakes but it cannot be good. I don't know what it does to the underside of cars but I know one thing from speaking to one of the former mechanical officers in London Transport. They have had to put shields underneath their transit cars because they catch on fire. They have grease loaded up there, and in the presence of sparks, they said that it smoulders. It is not really harmful; I mean it is not blazing, neither is it going to cause any kind of fire, but it sits there and it smoulders.

G.R. CATALDI: I agree. There have been tests, particularly on the Seaboard System, on well lubricated rails on a steep downgrade. They were quite able to handle a heavy train in braking. Quite a few of the lubricators do put too much grease out and quite a bit of study needs to be done yet on how it should be done, both equipment-wise and adjustment-wise. I am not saying that lubrication is better than modified trucks; I am just saying that it is an alternative research area. I don't know that either one of them is necessarily better.

J.W. HORWAT: Rail lubrication attacks only one part of what I have just talked about, and that is the wheel wear. Of course that is where the biggest payback is right now, but lubrication in itself will not enable an increase in track speed. Neither will a few cars with modified trucks. The difference is, that given sufficient numbers of cars with modified trucks, you have the capability to run faster and still save the wheel. Now I don't know how many people have done rail lubrication tests around the Manitoba area, but I lived in Winnipeg and when it gets cold, nothing flows, so I don't know how good rail lubricators are. Nevertheless, thank you.

# RADIAL AXLE FREIGHT CAR TRUCK TEST

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## ABSTRACT

The Department of Research and Development of CP Rail conducted in-service evaluation tests of Barber Scheffel and DR-2 self steering trucks. The Barber Scheffel trucks introduced into service in January, 1982 have accumulated close to 400,000 miles of revenue service operation. The DR-2 trucks have accumulated 150,000 miles of revenue service operation.

This paper discusses the results of wheel wear measurements carried out on the Barber Scheffel and the DR-2 self steering trucks. The results of a radial truck tear-down inspection are presented and discussed. A brief description of laboratory fatigue testing with DR-2 steering arms is also presented.

As part of this test program, other retrofit freight car trucks were also evaluated in 1984 and 1985, for high speed stability and curving performance. The UTDC frame-braced 100-ton truck and the 70-ton rigidized elasto cushion trucks were tested. The results are presented.

In 1986 CP Rail introduced the first trainset of coal cars equipped with Barber Radial and DR-2 trucks into revenue service. A brief description of the proposed 1986 test program is presented.

## 1. INTRODUCTION

The Department of Research and Development of CP Rail conducted, in recent years, a series of tests to evaluate the performance of "new generation" freight car trucks.

In 1978 a test plan, consisting of two phases, was formulated in coordination with the Mechanical Department of CP Rail. The first phase consisted of field testing aimed at obtaining quantitative data on the performance of various types of improved truck designs. During this phase, Barber-Scheffel, DR-1, Devine Scales, Swing Motion and Ride Control trucks were examined.

The results of Phase I testing indicated that a number of "new generation" truck designs improve both curving and hunting performance compared to existing conventional 3-piece trucks.

As a result of these findings, the two "most promising" self-steering radial trucks, namely the Barber-Scheffel and the DR-2 (similar to DR-1) trucks were chosen for in-service evaluation in unit coal train operation. In 1982, five carsets of bathtub coal cars equipped with the Barber-Scheffel and another five with DR-2 trucks were introduced to revenue service testing. The results of wheel wear evaluation on wheels of these radial trucks are presented in this report.

As a continuation of research activities by CP Rail on radial trucks, the Research and Development Department undertook fixed testing in 1984 and 1985 to determine the curving and stability characteristics of UTDC frame braced and rigidized elasto cushion trucks. In 1986, five carsets of bathtub coal cars were equipped with the UTDC frame braced trucks and introducted to revenue service testing.

In 1986 CP Rail introduced a unit coal trainset equipped with radial trucks into service. A brief description of the proposed 1986 test program is presented.

## 2. IN-SERVICE TESTING OF BARBER-SCHEFFEL TRUCKS

Barber Scheffel trucks were introduced into revenue service testing in January, 1982. They were applied on five 100-ton bathtub coal cars in series CP 352349 to 352443, at CP Rail's Ogden Shops in Calgary. Wheel measurements and truck inspections were made every 60,000 miles. The Barber Scheffel truck is shown in Figure 1.

These trucks have accumulated close to 400,000 miles of service. A truck tear down inspection was carried out at Ogden Shops in Calgary in October, 1984. Measurements of truck bolster bowl diameter and carbody centre plate were collected. Wheel wear measurements were also carried out. Figures 2 and 3 show the wheel flange and tread wear as compared to conventional Barber S2-C trucks.

After 250,000 miles of service operation, the Barber Scheffel truck wheels exhibit very little flange wear, approximately 1/5 that of the wheels of control cars equipped with conventional trucks. The tread wear on wheels of the Barber Scheffel trucks is also lower than conventional truck wheels. After 250,000 miles the tread wear on these radial trucks was found to be 2/3 that of the conventional truck wheels.

Measurements of truck bolster bowl and carbody centre plate revealed, after 250,000 miles, wear in the range of 1/16" - 3/64". Roller bearing adaptor thrust shoulder wear was found to be .001 - .002 inches. The AAR condemning limit is .025 inches. These data indicate that minimum wear had occurred on Barber Scheffel truck components.

## 3. THE DR-2 SELF STEERING TRUCK TESTS

The second truck selected for revenue service evaluation was the DR-2 truck, which is basically a conventional truck with steering arms and shear pads over-the-bolster connections. In May, 1982, five carsets of bathtub coal cars in series CP 352849 to CP 352853 were equipped with the DR-2 trucks at National Steel Car in Hamilton.

These trucks were introduced to revenue service operation on the Pacific Region of CP Rail in June, 1982 and were placed together with the special radial truck test consist of Barber-Scheffel and Barber S2-C trucks.

Test cars equipped with DR-2 trucks with steering arms having link connections accumulated approximately 130,000 miles of service when an inspection revealed that the links connecting the steering arms were failing. However, until these failures wheel profile measurements were collected for comparison with the Barber Scheffel trucks. Figures 4 and 5 show the loss of wheel flange cross-sectional areas and wheel tread cross-sectional areas vs. mileage.

From Figure 4 it is evident flange metal loss is considerably lower for both DR-2 and Barber-Scheffel truck wheels compared to conventional truck wheels. Wheels of both types of radial trucks exhibited approximately 20% of the flange wear developped on control car wheels.

Figure 5 shows the plot of the tread wear area reduction versus service mileage. There is a clear distinction between the tread wear patterns for both radial trucks as compared to conventional trucks. The average tread wear on wheels of the DR-2 and Barber-Scheffel trucks was found to be 60% that of the control car wheels with conventional trucks.

The DR-2 self-steering trucks were re-introduced into revenue service testing with a new design of the steering arm connection incorporating a pin/bushing arrangement as shown in Figure 6. These cars have now accumulated close to 150,000 miles of revenue service testing. They were introduced to revenue service testing in November, 1984.

The need to quantify the DR-2 steering arm in-service load environment for use in fatigue testing of the steering arm prompted CP Rail research to collaborate with Dofasco to collect these data. Field tests were carried out with coal cars CP 35852 and CP 35853 to measure the magnitude and frequency of occurance of DR-2 steering arm lateral and torque loads.

The load spectrum obtained from the instrumented DR-2 steering arm indicated that a maximum alternating load of 11,250 lbs. and a maximum alternating deflection of 0.972 inches occurred during loaded unit coal train return trip from Fording to Revelstoke on the Pacific Region.

Fatigue tests were carried out on the DR-2 steering arm at Dofasco's laboratory where a special fatigue test rig had been set up. The load environment on the DR-2 steering arm collected during the service testing was utilized to reconstruct field conditions in the laboratory tests.

The length of the test was based on AAR guidelines of a 3 million mile life for unit coal train equipment. The steering arm with integral adaptor successfully completed the fatigue tests.

## 4. UTDC FRAME BRACED TRUCK STABILITY AND CURVING PERFORMANCE TESTS

As a continuation of research by CP Rail on radial and premium trucks, the Research and Development Department undertook a field test program in the fall of 1984 to determine the curving and stability characteristics of UTDC frame braced trucks equipped with shear pads of 15,000 lbs./inch. Subsequent tests were carried out in 1985 on the same section of track near Calgary to quantify high speed stability performance of UTDC frame braced trucks equipped with shear pads of 25,000 lbs./inch.

The UTDC frame bracing hardware may be retrofitted to the conventional 100-ton Barber S2 3-piece truck. The truck side frames are held rigid by the addition of diagonal frame-bracing as illustrated in Figure 7. The diagonal braces between the two side frames are mounted resiliently in brackets welded to the side frames. Elastomeric shear pads at the axle/side frame bearing adaptors provide low wheelset yaw stiffness for good steering performance.

Tests to determine curving performance were carried out on a 5 degree curve at Mileage 12.4 on the Laggan Subdivision. A wheelset angle-of-attack measuring system developed by CP Rail Research was used, and wheel/rail forces were measured by strain gauges attached to the rails. As reference, the Barber S2-C truck with centre plate extension pads (C-peps) was also tested for curving performance. A significant reduction in angles-of-attack of the leading axle for the UTDC truck was observed.

In terms of stability performance, the UTDC truck equipped with 15,000 lbs./inch pads did not show better stability characteristics than conventional trucks when tested with service worn wheels. The truck equipped with 25,000 lbs./inch elastomeric pads showed superior high speed stability than that equipped with pads of 15,000 lbs./inch stiffness.

CP Rail introduced 5 carsets of bathtub coal cars equipped with the UTDC frame braced trucks with 30,000 lbs./inch LC pads to unit coal train service on the Pacific Region in March, 1986. Wheel wear and truck in-service performance will be evaluated for comparison with other radial trucks.

## 5. RIGIDIZED ELASTO CUSHION TRUCK TESTS

70-ton Barber S2-C trucks, rigidized by means of a shear plate applied between the side frames of the truck to prevent parallelogramming, were tested for high speed stability and curving performance. The shear plate is bolted to side frame extensions welded to the truck side frames as illustrated in Figure 8. The trucks were equipped with elastomeric shear pads of 25,000 lbs./inch shear stiffness at the axle/side frame bearing adaptors.

High speed stability tests showed that the rigidized elasto cushion truck has better stability characteristics than conventional 3-piece trucks. The rigidized elasto cushion trucks were stable to a maximum speed of 65 mph.

Curving performance test showed a substantial reduction in wheelset angle-of-attack of the leading and trailing axles of the rigidized elasto cushion trucks compared to the conventional 3-piece truck wheelsets.

## 6. IN SERVICE EVALUATION OF UNIT COAL TRAIN WITH RADIAL TRUCKS

The results of wheel wear evaluation of Barber Scheffel and DR-2 trucks indicated that these 100-ton radial trucks will yield substantial savings in wheel flange wear and to a lesser extent savings in wheel tread wear.

CP Rail has now introduced a unit coal train equipped with radial trucks to service. Tests are being planned to evaluate the performance of this unit coal train equipped with the Barber Radial and DR-2 trucks as compared to one equipped with conventional Barber S2-HD trucks. The following tasks have been developed for testing of this trainset now operating on the Pacific Region:

1. Rail Wear: Determine the savings in rail wear which would result from the use of radial trucks.

2. Wheel Wear: Ensure that the wheel wear savings on the radial truck equipped trainset are consistent with those previously measured on wheels of the Barber Scheffel and DR-2 trucks.

3. Train Energy: Determine the fuel savings which may be realized by the use of radial trucks.

4. Stability Performance: To assess the relative stability of Barber Radial and DR-2 trucks with service worn wheels.

5. **General Maintenance Monitoring:** Ensure, by regular inspection, that the performance of various components of the radial trucks is adequate.

## REFERENCES

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2. "Radial Axle Truck Tests - Volume 2", Khatchadourian V., Gonsalves R., Izbinsky G., D'aoust D., Department of Research and Development, CP Rail, Report number TP 6859E, August, 1985.

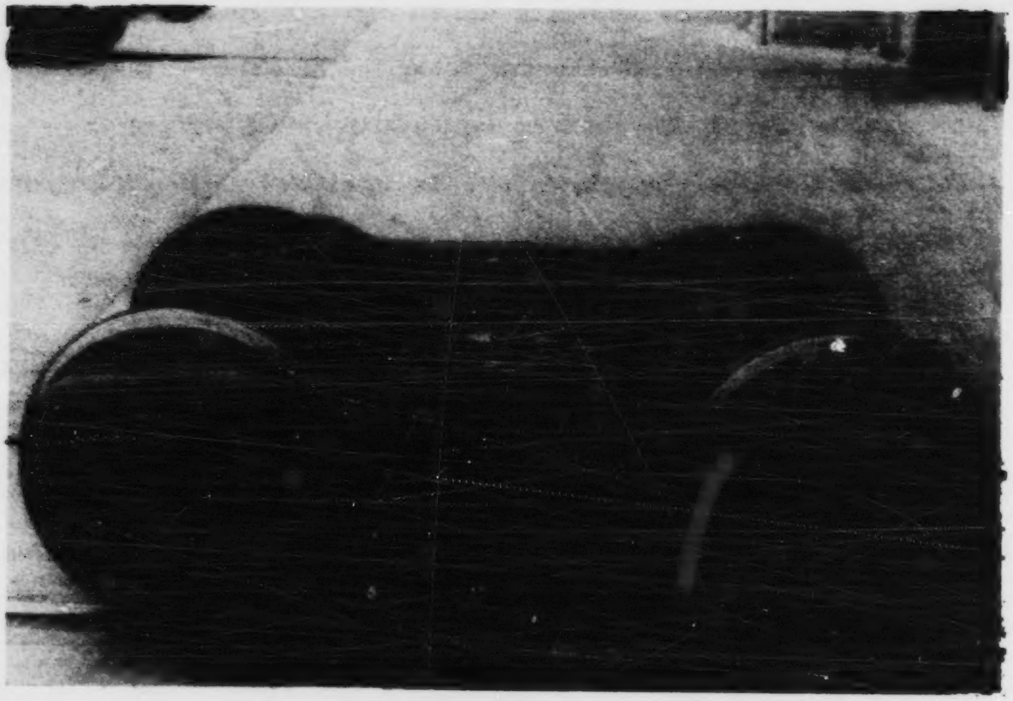
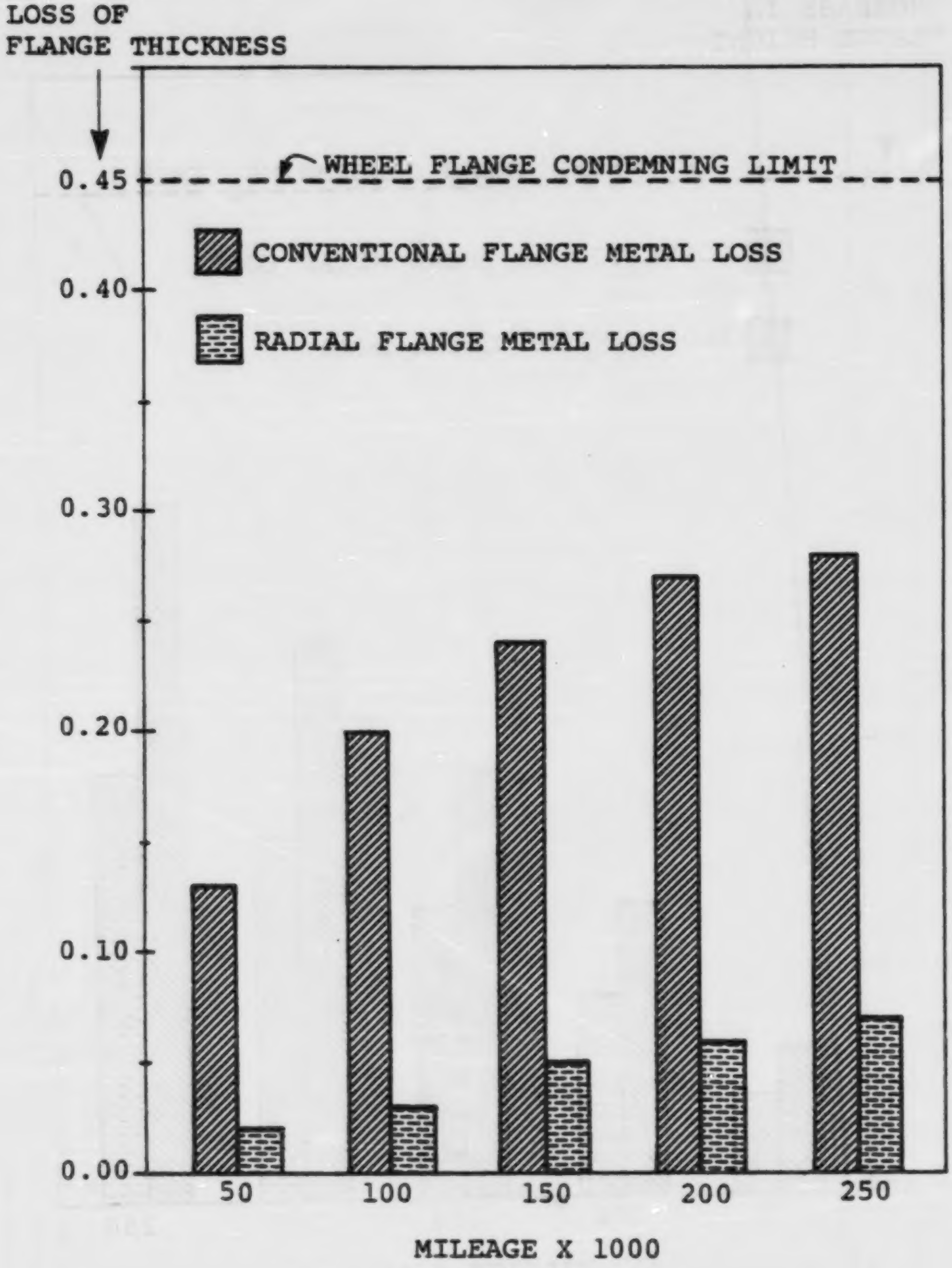
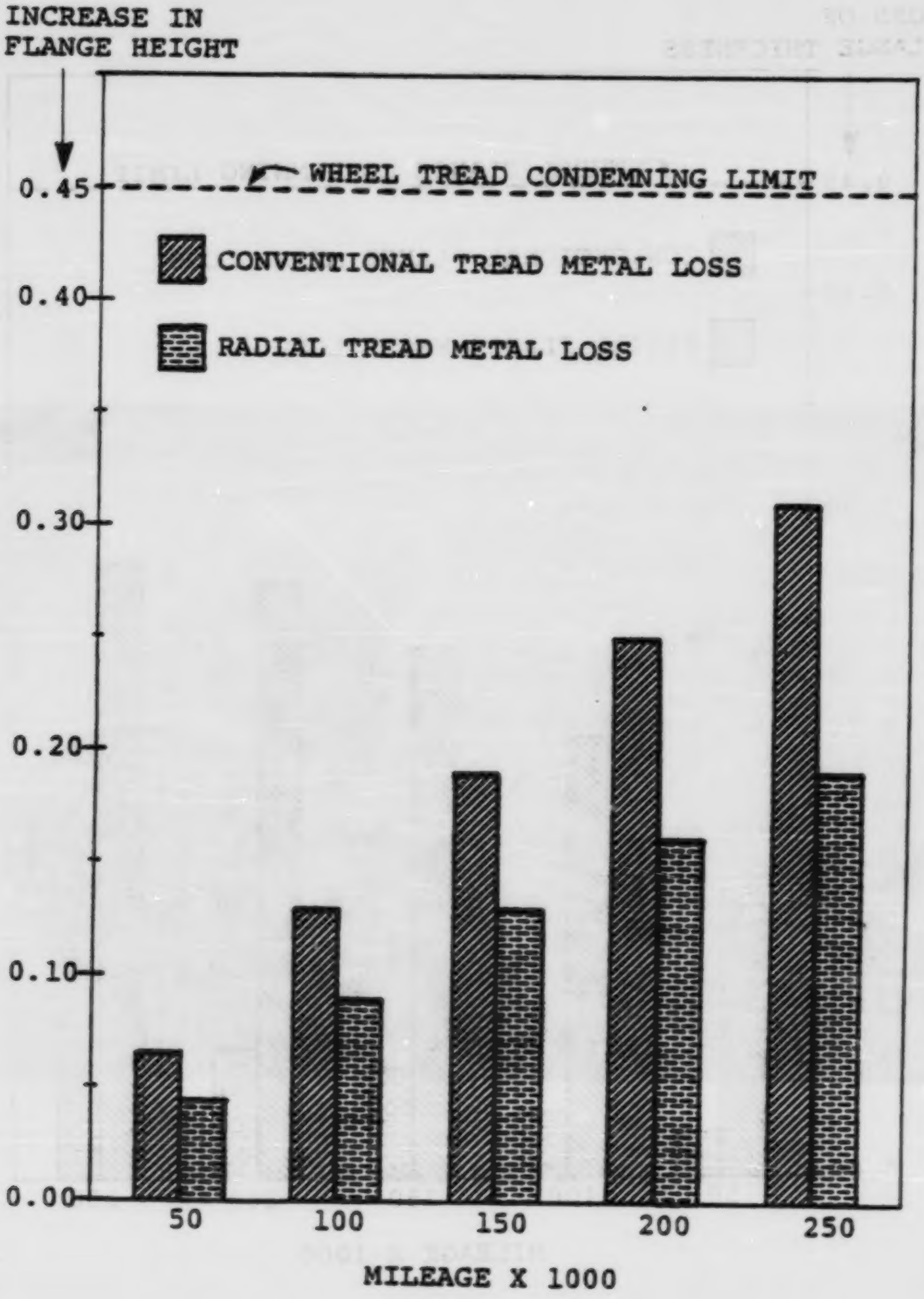


Figure 1: THE BARBER SCHEFFEL SELF-STEERING TRUCK



LOSS OF FLANGE THICKNESS VS MILEAGE

Figure 2



INCREASE IN FLANGE HEIGHT VS MILEAGE

Figure 3

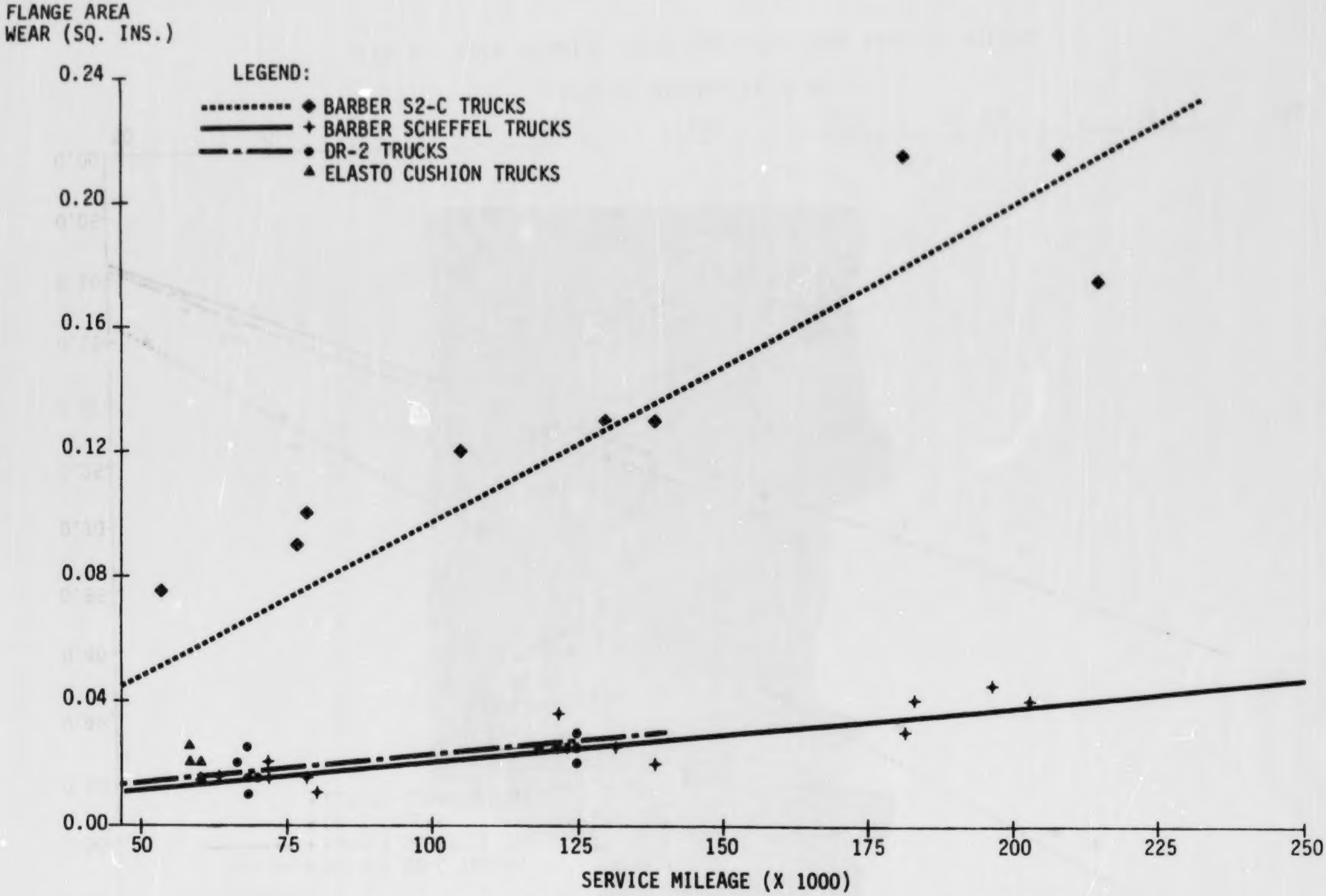


FIG. 4 : LOSS OF WHEEL FLANGE CROSS-SECTIONAL AREA VS. MILEAGE

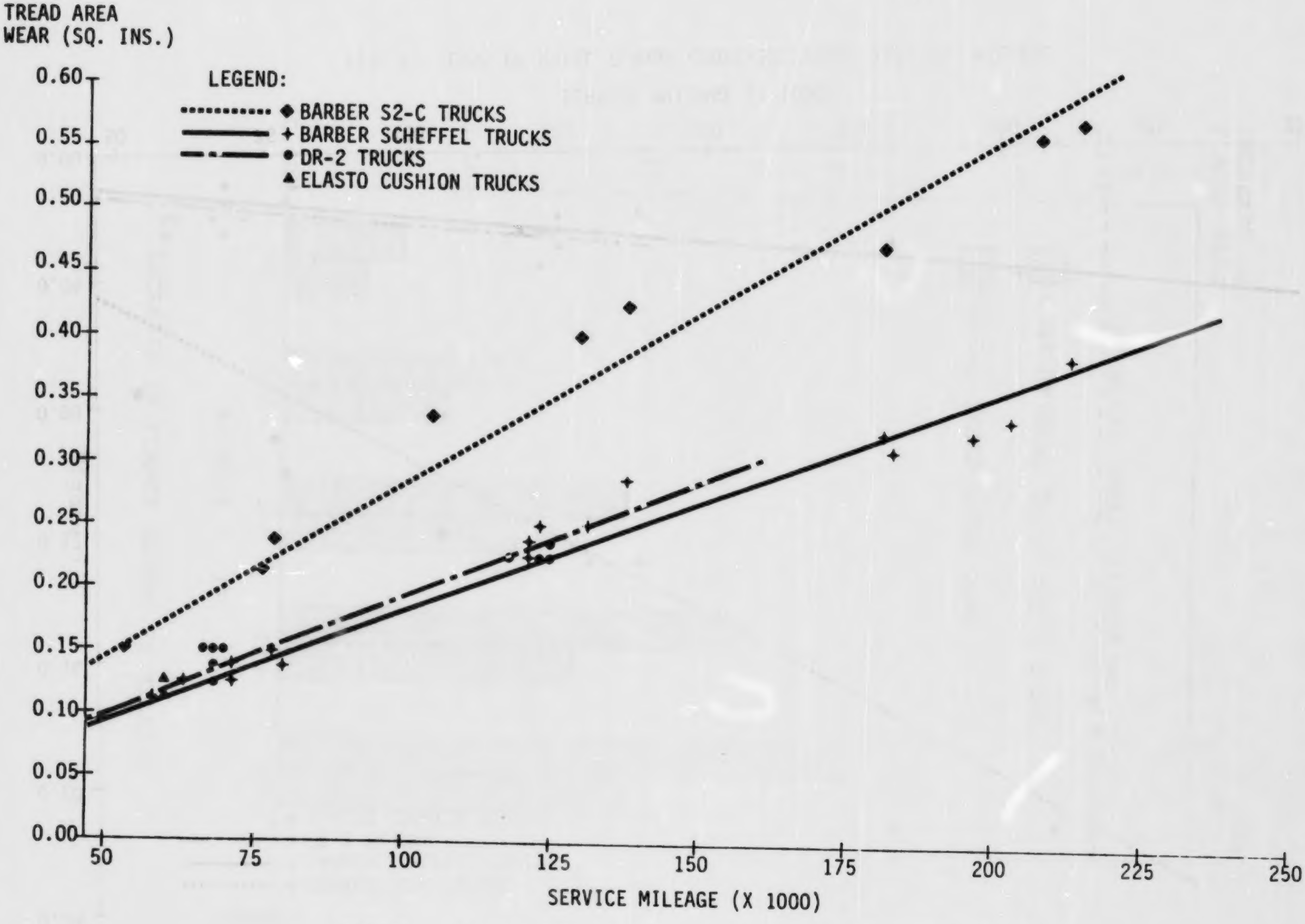


FIG. 5 : LOSS OF WHEEL TREAD CROSS-SECTIONAL AREA VS. MILEAGE

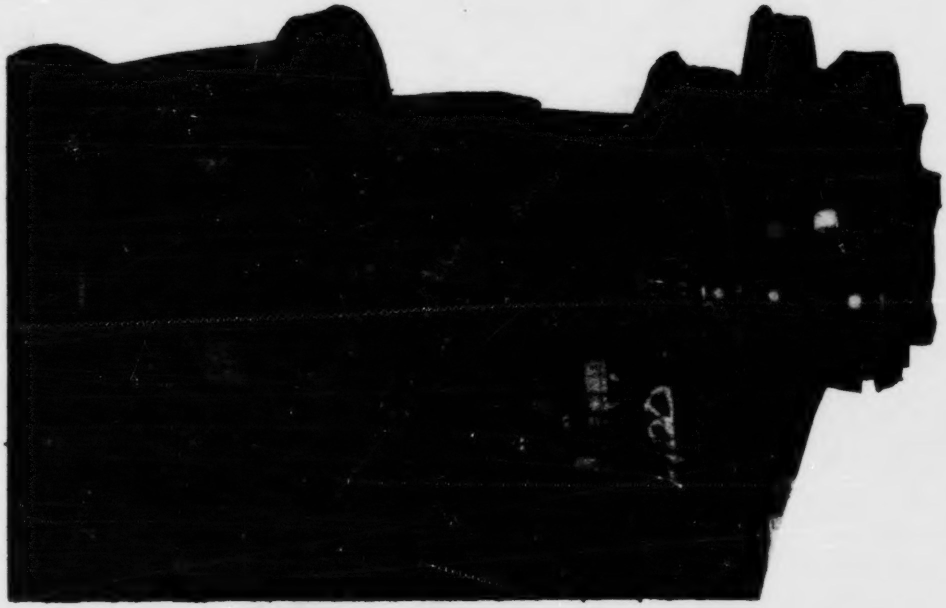


Figure 6: THE DR-2 SELF-STEERING TRUCK

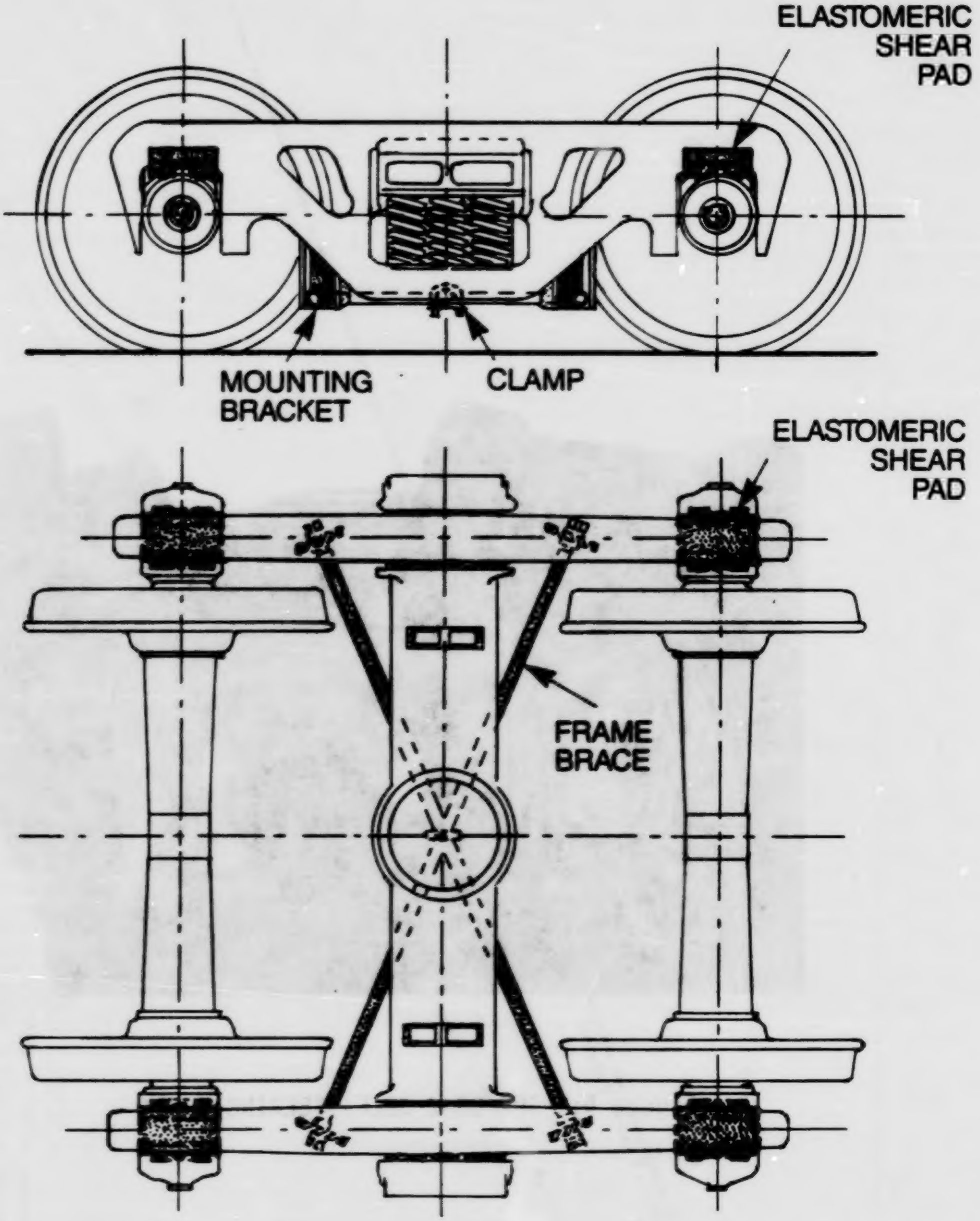

ELASTOMERIC SHEAR PAD
MOUNTING BRACKET
CLAMP
ELASTOMERIC SHEAR PAD
FRAME BRACE

FIG. 7: **UTDC FRAME BRACED TRUCK**

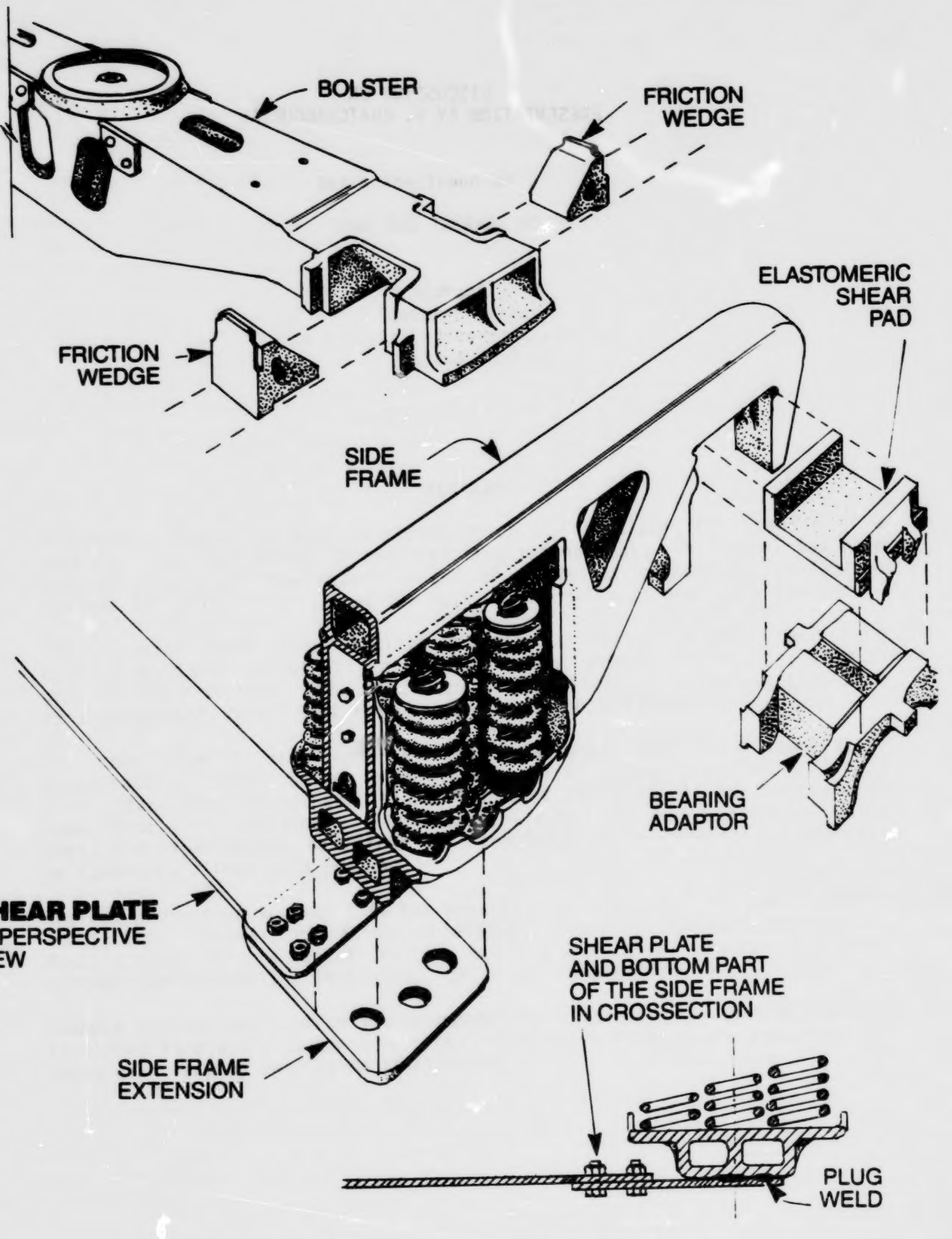

BOLSTER
FRICTION WEDGE
ELASTOMERIC SHEAR PAD
FRICTION WEDGE
SIDE FRAME
BEARING ADAPTOR
SHEAR PLATE IN PERSPECTIVE VIEW
SHEAR PLATE AND BOTTOM PART OF THE SIDE FRAME IN CROSSECTION
SIDE FRAME EXTENSION
PLUG WELD

FIG. 8: **RIGIDIZED ELASTO CUSHION TRUCK**

## DISCUSSION ON
## PRESENTATION BY V. KHATCHADOURIAN

No questions asked

# TANK-CAR THERMAL MODEL

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## ABSTRACT

A computer model has been developed which can simulate the response of a tank-car, and its lading, to external fire impingement. This model has been developed to study the effectiveness of a variety of thermal protection systems for protecting against the risk of thermally induced tank rupture.

The computer model can simulate a rail tank-car, or any other long cylindrical tank, filled with a number of light petroleum products, such as propane and propylene. The model can simulate both an engulfing type fire or a torch type fire. Tank roll and pitch can be accounted for.

The model can predict tank internal pressure, tank wall temperature distributions, mean lading temperatures, relief valve flow rates, liquid level, tank wall stress conditions, and tank failure, all as functions of time from fire ignition. The computer model has been validated using available experimental data from full and fifth-scale fire tests conducted on tank-cars filled with propane.

Thermal protection systems that can presently be simulated include: thermal insulation, thermal radiation shielding, internal thermal protection, fusible plug pressure relief devices, and pressure relief valves. The above systems can be modelled separately, or in any combination.

Example validation results are presented for unprotected tanks exposed to engulfing fire and a torch type fire. Simulation results are presented for tanks with varying insulation thicknesses.

# TANK-CAR THERMAL MODEL

## THE MODEL

The Tank-Car Thermal Computer Model (TCTCM) is a digital computer based model capable of simulating the response of a tank-car and its lading to conditions of external fire impingement (engulfing fire or torch type fire). The model is basically a two-dimensional representation of a circular cylindrical tank (i.e., axial gradients and end effects are not accounted for). However, the model has a pseudo-3D operating mode so that pitched and rolled tanks can be analyzed.

The TCTCM is versatile in that it can consider a wide range of system configurations. In addition to being able to consider different fire types and tank orientations, the model is also capable of simulating a number of different ladings and thermal protection devices. Table 1 summarizes the various configurations that can be considered. Of course, in addition to the items shown in Table 1, the TCTCM requires input of boundary conditions such as initial temperature, initial fill conditions, relief valve set pressure, etc., which can be set to a range of physically reasonable values.

| LADING TYPE | THERMAL PROTECTION | TANK ORIENTATION | FIRE CONDITIONS |
|---|---|---|---|
| Propane | Thermal Insulation | Variable Roll | Engulfing Fire |
| Butane | | | |
| Pentane | Thermal Radiation Shielding | Variable Pitch | Torch Type Fire |
| Propylene | Special Pressure Relief Devices | | |
| | "Explosafe" | | |

**TABLE 1: SUMMARY OF SYSTEM CONFIGURATIONS CONSIDERED BY THE TCTCM**

Therefore, the TCTCM is capable of analyzing a very wide range of tank/lading/protection/accident scenarios which makes it a valuable tool in such exercises as risk assessment.

The TCTCM can consider two tank scales as described below:

| | | | |
|---|---|---|---|
| Full-Scale | Length | = | 18.3 m |
| | Diameter | = | 3.05 m |
| | Wall Thickness | = | 0.016 m |
| | Capacity | = | 125 $m^3$ |
| One-Fifth Scale | Length | = | 3.66 m |
| | Diameter | = | 0.61 m |
| | Wall Thickness | = | .018 m |
| | Capacity | = | 1.0 $m^3$ |

The full-scale model represents a US DOT 114A340W tank-car. The one-fifth scale is also based on the above specification.

The TCTCM is capable of predicting tank internal pressure, tank wall temperature distributions, relief valve flow rates, tank fill level, and tank wall stresses and strength, all as functions of time from fire ignition. These various outputs define the response of the tank/lading system and provide valuable information for the design of a thermal protection system.

The model is made up of a series of submodels simulating the following processes:

i) flame to tank heat transfer;

ii) heat transfer through the tank wall and associated coverings;

iii) interior-surface to lading heat transfer;

iv) thermodynamic process within the tank;

v) thermodynamic properties of the lading;

vi) pressure relief device operating characteristics;

vii) wall stresses and material property degradation, and,

viii) tank failure.

The flame to tank heat transfer submodels can account for either an engulfing pool fire or a two-dimensional torch. The pool fire model accounts for thermal radiation and convection. The thermal radiation is calculated as a function of the circumferential position on the tank as described in Reference (1). The convection calculations are based on empirical relations for convection to horizontal cylinders in a crossflow. The torch submodel is based on empirical relations for a jet impinging on a flat plate. The geometry of the jet/plate system in the submodel is similar to the US DOT Transportation Test Centre Torch Simulator as described in Reference (2).

The heat transfer through the tank wall and associated coverings is represented using finite difference techniques. The finite difference solution accounts for pure conduction through the tank wall and insulating layers, and pure conduction, convection and radiation in the Explosafe regions and in the gap between the wall and any radiation shielding. The finite difference solution also accounts, of course, for the heat transfer from the fire to the tank outer surface and from the tank inner surface to the lading.

The interior surface heat transfer submodels account for convection and radiation in the vapour space, and convection and boiling in the liquid region. The radiation calculations are based on the assumption that the wall communicates only with the lading. The convection and boiling coefficients are based on empirical relations for inclined flat surfaces.

The thermodynamic process submodel is based on fundamental thermodynamics and treats the lading as three distinct regions: the vapour space, the liquid boundary and the liquid core. It is assumed that the vapour and liquid boundary (near wall, and free surface) are in thermodynamic equilibrium and saturated, the core is assumed to be subcooled initially, but after some period of venting it is assumed to be in equilibrium with the liquid boundary and vapour space. This submodel requires the setting of two empirical constants, the liquid boundary thickness, and the energy partition factor that determines how much of the fire heat is transferred into the vapour and liquid boundary, and how much it is transferred to the liquid core. These constants have been determined from one set of fire test results and have remained unchanged for all subsequent validation runs and simulations. In the submodel it is assumed that the energy for venting comes from the vapour and liquid boundary, and this energy drain is one reason that the liquid core eventually reaches equilibrium with the other regions.

The thermodynamic and transport properties of the lading are based on the Starling equation of state, and on available material property data, respectively.

The pressure relief valve submodel accounts for both the mechanical action of a relief valve and the fluid mechanics. The valve mechanics are accounted for using a steady state model. Valve cycling dynamics are not accounted for explicitly but rather implicitly by having a model valve that sits partially open to represent the reduced flow capacity during cycling, and fully open when in reality the valve is fully open. The opening fraction is determined by the lading vaporization rate which relates, of course, to the valve cycling frequency. The valve flow submodels can account for dry vapour flow and for frozen liquid flow.

The wall stresses are calculated at the point on the wall circumference which experiences the highest temperature and includes pressure induced (hoop) stress and stresses due to radial temperature gradients in the tank wall. The tank failure analysis is based on the maximum normal stress theory of failure. Degradation in the wall material strength with increases in temperatures are accounted for using available data for tank-car steel.

Further technical details about these various sub-models are given in References (3) and (4).

## EXAMPLE SIMULATIONS

The results of three example simulations will now be presented to demonstrate the TCTCM capabilities.

The first simulation involves an unprotected rail tank-car exposed to an engulfing fire. Such a situation may occur in an accident involving the spill of flammable liquids. Presented along with the simulation results for this case is data obtained from a full-scale fire test conducted on a tank-car and reported in Reference (5). This case was actually one of several used in the validation of the TCTCM. Further details of the validation can be found in References (3) and (6).

The second simulation involves an unprotected tank exposed to a torch type fire such as might occur in an accident where the flare issuing from the relief valve of a neighboring tank carrying flammable fluids impinges on another tank. This simulation demonstrates how the TCTCM results compare favorably with actual fire tests on full-scale tanks, and tests conducted with specially designed equipment used to simulate torch fire environments for evaluating thermal insulation materials.

The third and final example presents the results of a series of simulations conducted to study the significance of varying the thickness of thermal insulation applied to a tank outer surface. Such an exercise might be performed to determine a cost effective insulation thickness on a storage or transport vessel.

## CASE 1: UNPROTECTED TANK EXPOSED TO AN ENGULFING FIRE

As already stated, this case was conducted as part of the TCTCM validation. The simulation involved a full-scale unprotected tank filled to 95% capacity with propane, exposed to an engulfing fire. The model inputs were chosen to closely match the conditions which existed in the actual fire test of a full-scale unprotected tank. The results of the simulation are presented in Figures 1 to 4 along with the data from the fire test.

Figure 1 presents the predicted and measured tank pressure. As can be seen from the figure, predictions are in good agreement with the measured pressures.

Figure 2 presents the predicted and measured wall temperatures at different circumferential locations. As can be seen, the agreement between predictions and measurements are generally quite good. Divergence between the predictions and measurements occur for the 30, 60 and 90° circumferential locations. This divergence is believed to be caused by variations in the fire conditions, caused by cross winds during the fire tests. The TCTCM is not quite capable of accounting for cross wind effects.

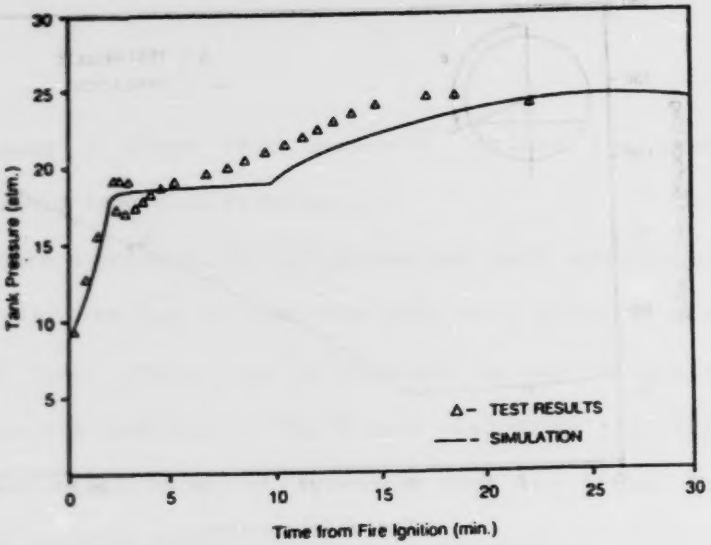

**FIGURE 1** PREDICTED TANK PRESSURE AND MEASURED TANK PRESSURE FOR UNPROTECTED TANK EXPOSED TO ENGULFING FIRE (DATA FROM REFERENCE 5)

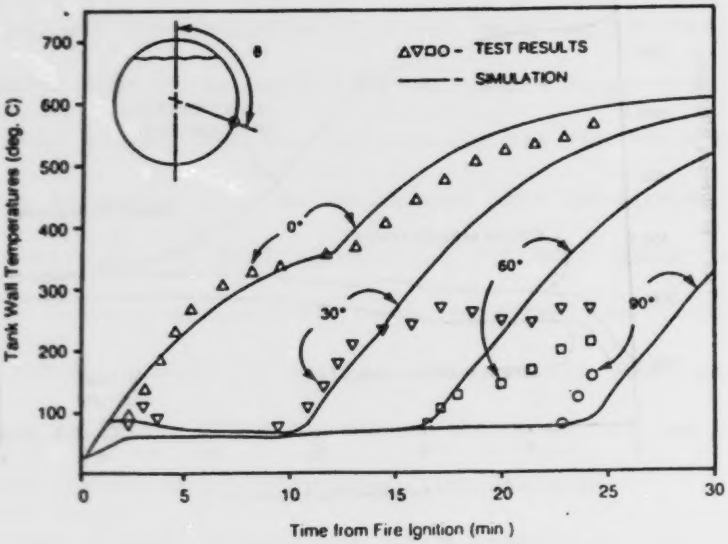

**FIGURE 2** PREDICTED WALL TEMPERATURES AND MEASURED WALL TEMPERATURES FOR UNPROTECTED TANK EXPOSED TO ENGULFING FIRE (DATA FROM REFERENCE 5)

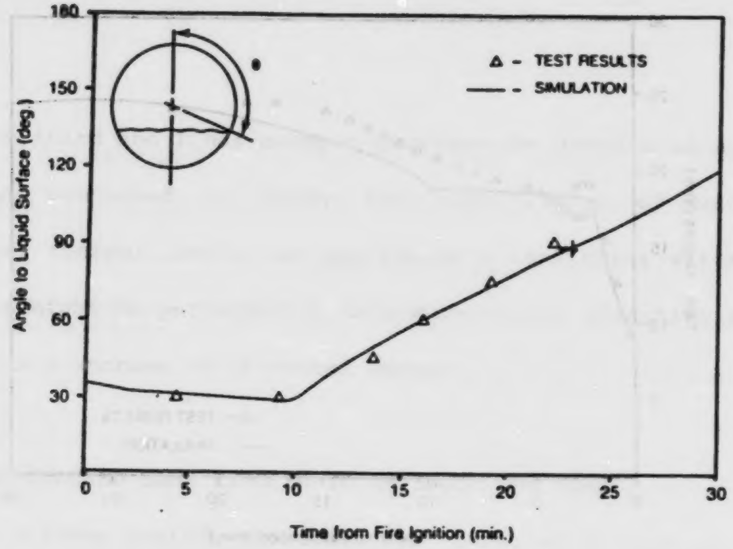

FIGURE 3 PREDICTED LIQUID LEVEL AND MEASURED LIQUID LEVEL FOR UNPROTECTED TANK EXPOSED TO AN ENGULFING FIRE (DATA FROM REFERENCE 5)

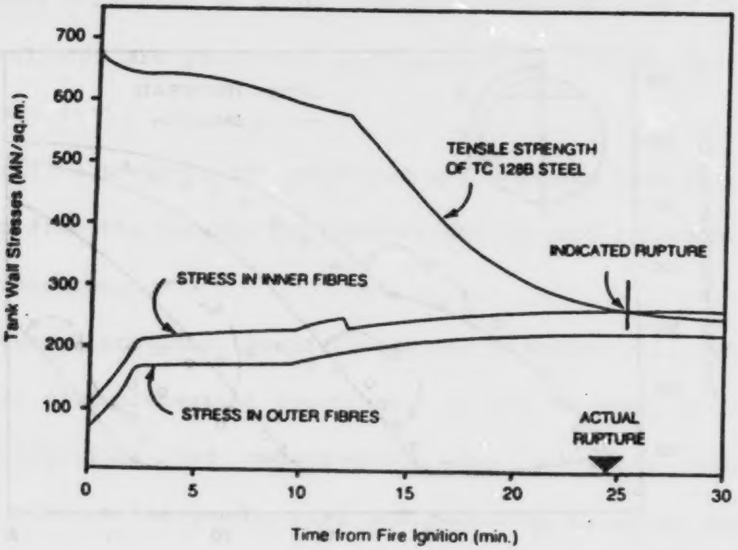

FIGURE 4 PREDICTED TANK WALL STRESSES AND MATERIAL STRENGTH FOR PREDICTED TANK EXPOSED TO AN ENGULFING FIRE (DATA FROM REFERENCE 5)

Figure 3 shows that agreement between the predicted and measured liquid levels is excellent.

Figure 4 presents the predicted tank wall material strength and stress levels. As can be seen the tank wall strength drops rapidly during the fire. This drop in strength is due to the temperature increases in the tank wall. The figure also shows that the predicted failure time is in excellent agreement with the actual failure time observed in the fire test.

## CASE 2: UNPROTECTED TANK EXPOSED TO A TORCH TYPE FIRE

Figure 5 presents a comparison between results obtained from the US DOT torch facility and the TCTCM. The figure shows results from three sources: a TCTCM simulation of a near empty unprotected tank-car; an actual torch test on an empty tank-car; and a torch test conducted on a bare steel plate. The test results for the two torch tests were obtained from Reference (2). As can be seen from the figure, the three sets of results are in good agreement. The bare plate tests were designed to replace the actual tests performed on tank-cars for evaluating thermal protection coating. The results shown in Figure 5 indicate that using the TCTCM can reduce the number of the torch fire tests on bare plates, or possibly even eliminate them.

Figures 6 to 9 present the TCTCM predictions for a tank-car filled to 95% capacity with propane, exposed to a torch type fire applied at 30° from tdc.

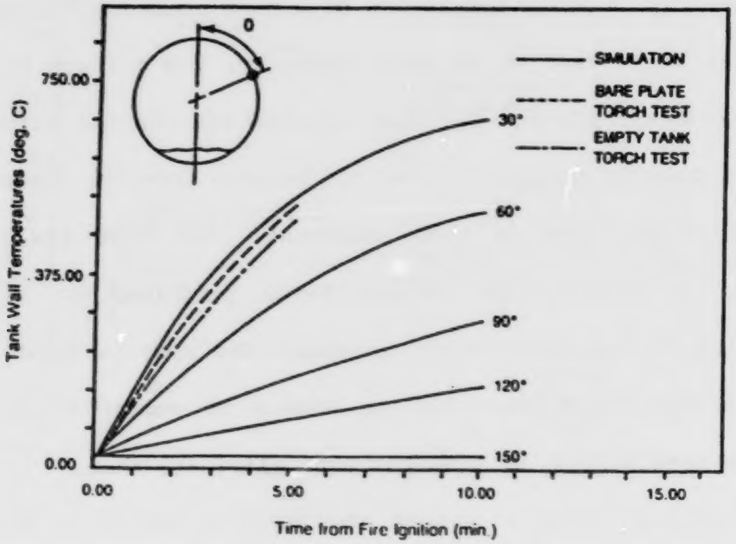

FIGURE 5 PREDICTED WALL TEMPERATURES AND MEASURED WALL TEMPERATURES FROM TORCH FIRE TEST (DATA FROM REFERENCE 2)

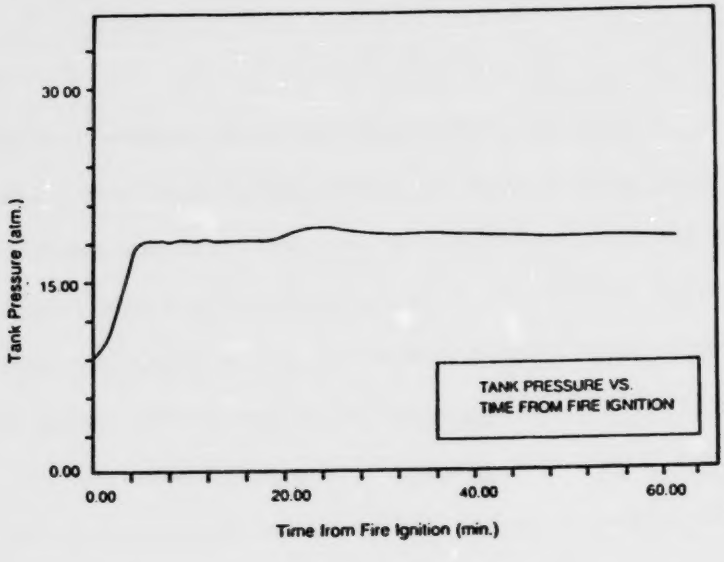

FIGURE 6 PREDICTED TANK PRESSURES FOR A TANK EXPOSED TO A TORCH FIRE APPLIED AT 30 DEGREES FROM THE TANK TOP-DEAD-CENTRE

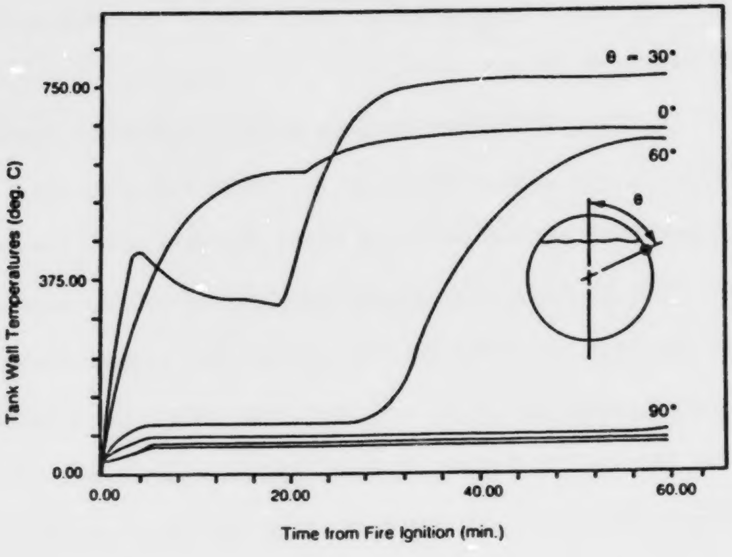

FIGURE 7 PREDICTED TANK WALL TEMPERATURES FOR A TANK EXPOSED TO A TORCH FIRE APPLIED AT 30 DEGREES FROM TDC

In this case the point of torch application is very close to the liquid level, which of course has a significant effect on how the system absorbs the heat from the torch. If the torch is applied above the liquid surface the heat from the torch stays in the tank wall and high wall temperatures result. If the torch is applied below the liquid level the heat is absorbed by the liquid lading and this results in a more rapid tank pressurization and lower tank wall temperatures. In either case, however, lading is released through the relief valve, causing the liquid level to drop, and eventually the torch will impinge the wall above the liquid level, resulting in high wall temperatures.

As can be seen in Figure 6, the tank pressure rises rapidly until the relief valve opens to maintain the pressure at the desired maximum level of 18 atm. (265 psi).

The wall temperature predictions in Figure 7 clearly indicate the effect of the liquid level on the wall temperatures. Initially the wall temperature at the point of torch application (30° from tdc) rises very rapidly because the torch is applied above the liquid level. However, as heat is added to the system the liquid level rises due to thermal expansion and frothing, and the wall responds to the cooling action of the rising liquid lading. As time goes on, the liquid level drops below the point of torch application because of venting and the wall temperatures once again rise to very high levels.

Figure 8 presents the predicted liquid level. The most important effect seen in the figure is the movement of the liquid level relative to the application point of the torch.

Figure 9 presents the wall material strengths and stress levels. As can be seen from the figure, tank failure is probable after approximately 26 minutes into the fire. This time to failure is dictated by the peak wall temperature which is, of course, significantly affected by the location of the liquid level. As can be seen from the figure, the wall material strength drops rapidly because the torch is applied above the liquid level, but, as the liquid level rises, the wall at the point of torch application is cooled by the liquid and therefore it regains some of its original strength. Eventually, however, the liquid level drops below the torch application point and the resulting high temperatures degrade the material properties to a level sufficient to cause failure.

## CASE 3: TANKS WITH DIFFERENT THICKNESSES OF THERMAL INSULATION

This series of simulations involves three tank-cars, with different thicknesses of thermal insulation: 1.3 mm, 2.5 mm and 6.3 mm. The properties of the insulating material are similar to those of asbestos. Each tank is filled to 95% capacity with propane and is exposed to an engulfing fire. The results are presented in Figures 10 to 13.

Figure 10 presents the predicted pressures for the different cases considered. As expected, the simulations indicate that the initial rate of tank pressurization is most rapid for the tank with the thinnest layer of insulation. However, because all three simulations assumed the use of the same pressure relief device, the pressures

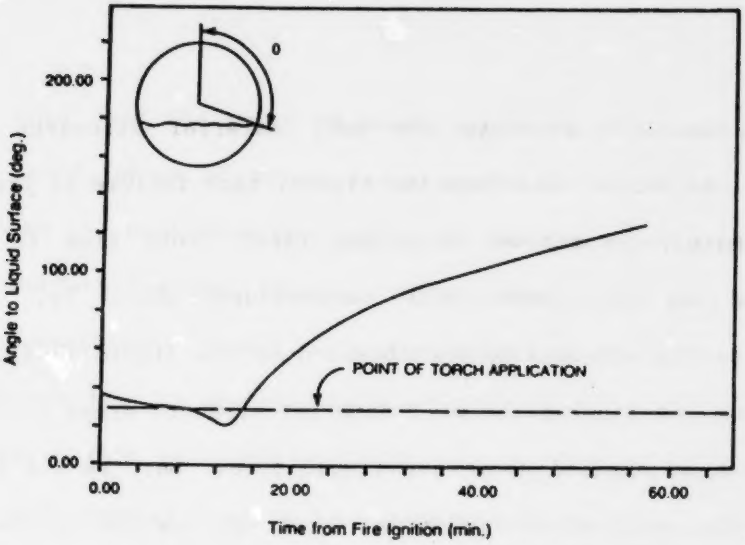

FIGURE 8 PREDICTED LIQUID LEVELS FOR A TANK EXPOSED TO TORCH FIRE APPLIED AT 30 DEGREES FROM TDC

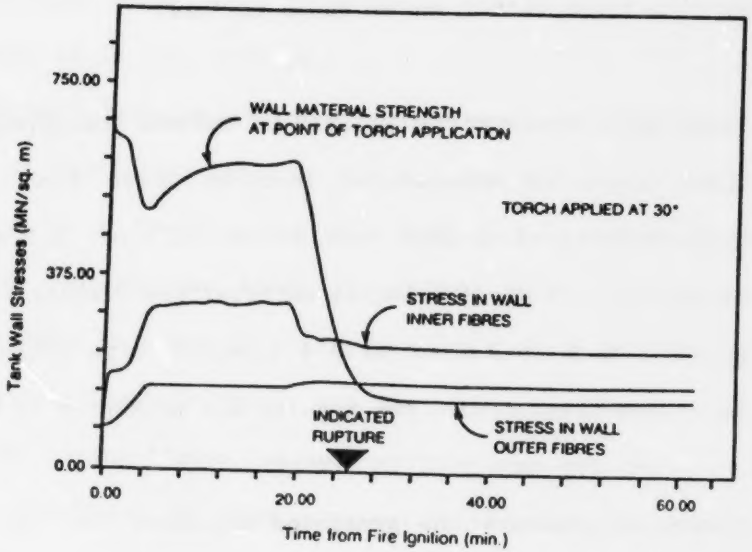

FIGURE 9 PREDICTED TANK WALL STRESSES AND TANK WALL MATERIAL STRENGTHS FOR A TANK EXPOSED TO A TORCH FIRE APPLIED AT 30 DEGREES FROM TDC

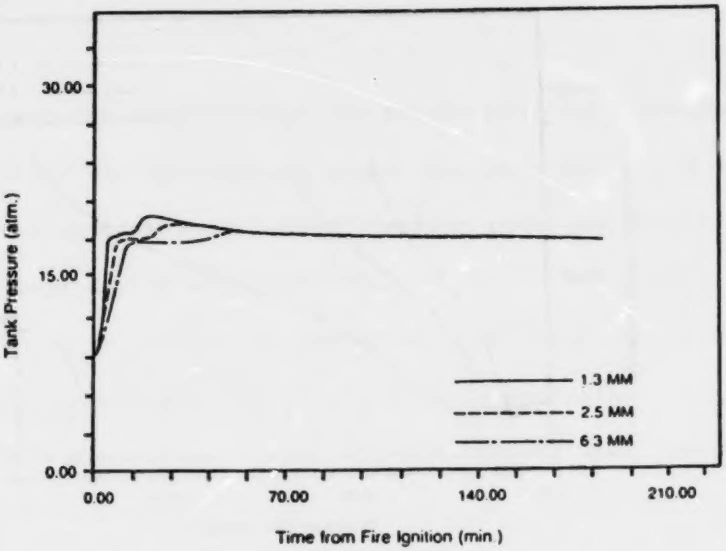

FIGURE 10 PREDICTED TANK PRESSURES FOR INSULATED TANKS WITH DIFFERENT THICKNESS OF INSULATION, EXPOSED TO AN ENGULFING FIRE

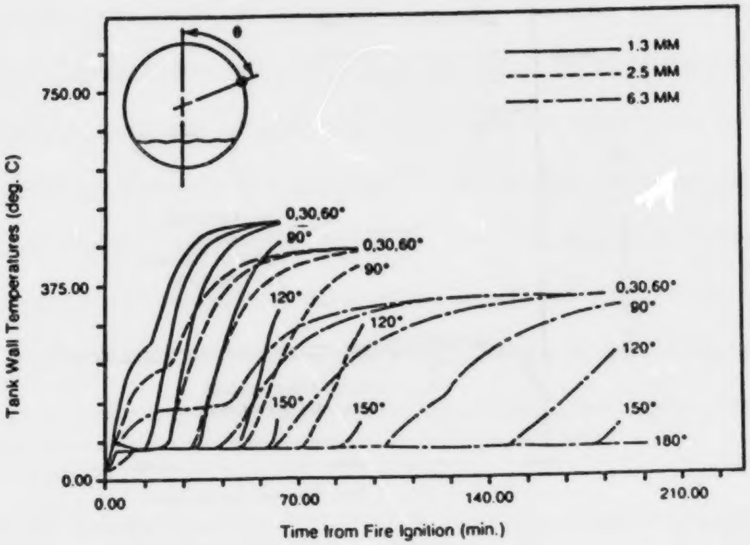

FIGURE 11 PREDICTED TANK WALL TEMPERATURES FOR INSULATED TANKS WITH DIFFERENT THICKNESSES OF INSULATION, EXPOSED TO AN ENGULFING FIRE

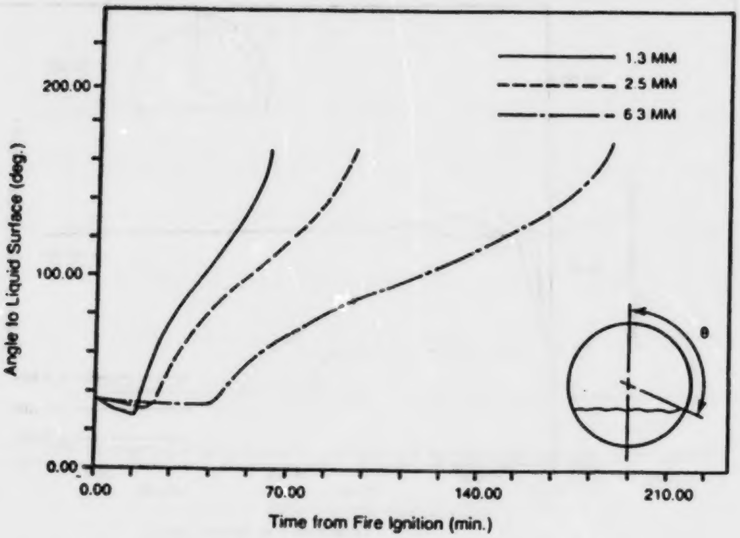

FIGURE 12 PREDICTED LIQUID LEVEL OF INSULATED TANKS WITH DIFFERENT THICKNESSES OF INSULATION, EXPOSED TO AN ENGULFING FIRE

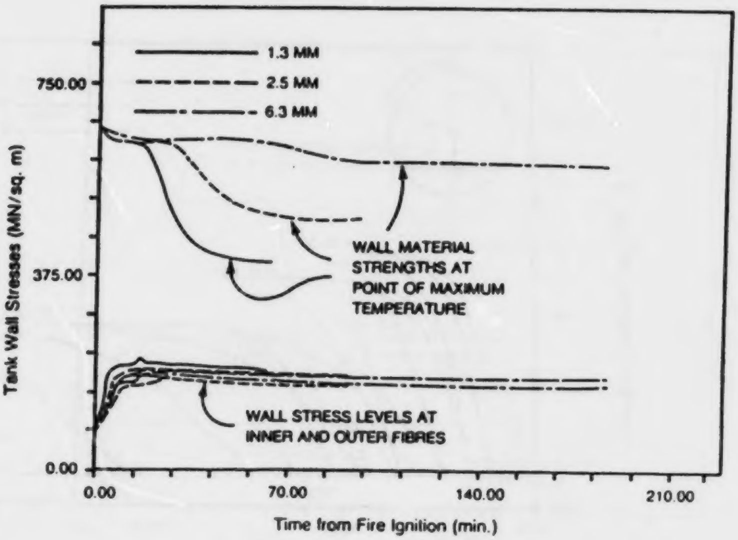

FIGURE 13 PREDICTED TANK WALL STRESSES AND TANK WALL MATERIAL STRENGTHS FOR INSULATED TANKS WITH DIFFERENT THICKNESSES OF INSULATION, EXPOSED TO AN ENGULFING FIRE

eventually reach the same values. It should be noted, however, that the level portion of the pressure plots indicate valve cycling, and that the cycle frequencies and, hence, venting rates are higher for the cases with thinner layers of insulation.

Figure 11 presents the predicted wall temperatures for the different cases considered. As can be clearly seen, the thickness of insulation has a significant effect on wall temperatures, in terms of peak valves and time scales.

Figure 12 presents the predicted liquid levels for the different cases considered. As expected, the tank with the thinnest coating and thermal protection emptied the fastest. This is consistent with the fact that the venting rate is highest for the case with the thinnest layer of insulation. An interesting thing to note is that the thicker the insulation, the longer the tank remains partially full of propane. As long as there is propane left, the explosive potential, in the event of a rupture is high. This is not to say that a heavily insulated tank is more dangerous than an uninsulated tank. It simply notes that a full tank is potentially more dangerous than an empty tank in the event of a rupture, and that a heavily insulated tank will hold its contents longer.

Based on simulation results, an unprotected tank reaches the half full point at approximately 22 minutes and an insulated tank (6.3 mm asbestos insulation) will reach the half full mark after approximately 90 minutes. In both cases the tank internal pressures are similar because of the effectiveness of pressure relief valves.

Therefore if both tanks were to rupture at the half full mark, similar explosions would result, and therefore one could argue that the potential for disaster lasts much longer for an insulated tank.

The above argument, of course, falls down because the insulated tank is designed not to rupture due to high wall temperatures. Case histories to date have shown that insulation has very effectively addressed the problem of thermally induced ruptures. However from a risk assessment standpoint one should not only consider case histories. If for some reason a tank's insulation is damaged (due to an accident or a lack of proper maintenance), or if a tank's structural integrity is reduced due to some kind of impact during the accident, then it is possible that a rupture could occur. One possible method of reducing this risk is to include some kind of backup system that rapidly vents the lading in the event of a prolonged, intense, engulfing fire.

Figure 13 presents the predicted tank wall material strengths and wall stress levels. As can be seen, the stress levels are similar for the three tanks, but the material strengths differ significantly. The differences in the material strengths are due to the differences in the predicted wall temperatures. The thinner the insulation, the higher the peak wall temperatures and the lower the material strength. As can be seen in Figure 13 the material strength for the tank with 6.3 mm of insulation is almost unaffected during the fire. This indicates that there would be little justification for increasing the insulation thickness beyond 6.3 mm, in this particular case. The figure also shows that all three tanks survived the fire simulation and the tanks emptied safely. It could therefore be argued that all three thicknesses provided satisfactory thermal protection.

## CONCLUSIONS

A computer model has been developed which can simulate the responses of a pressurized cylindrical tank, and its lading, to external fire impingement. The model has been validated using data obtained from a number of full and one-fifth scale fire tests of both unprotected and thermally protected tanks.

The computer model is intended as an aid in the design of thermal protection systems. It allows a designer to quickly compare a number of different system configurations. The model also makes it possible to compare complex thermal protection systems that incorporate several different thermal protection devices. The model can lower the costs and time involved in evaluating and developing new technologies proposed for reducing the risk of tank explosions.

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2) Anderson, C.E.; Rail Tank Car Safety by Fire Protection, 6th International Fire Protection Seminar, 1982.

3) Birk, A.M.; The Development and Validation of a Mathematical Model of a Rail Tank-Car Engulfed in a Fire, Ph.D Thesis, Queen's University, Kingston, Ontario, Canada 1983.

4) Birk, A.M.; User Documentation for the Rail Tank-Car Thermal Analysis Program, Davis Engineering Ltd., Report No. 83-29, Ottawa, Ontario, Canada, March 1985.

5) Railroad Tank Car Safety Research and Test Project; Phase II Report on Full-Scale Fire Tests, AAR-RPI, RA-11-6-31, AAR-R-201, US6 AFI 17-75 ENG(BK).

6) Birk, A.M.; Validation and Testing of the Tank-Car Thermal Analysis Program, Davis Engineering Ltd., Transport Canada Report No. TP6693E, March 1985.

## DISCUSSION ON
## PRESENTATION BY A.M. BIRK

C. COMISKEY (PROCOR): I read your full report and I congratulate you on a very well written and very easily understood paper. I guess the thing that disappointed me was to look at the torch fire tests in your comparison. In your evaluation of them, that is the Pueblo test, concerning the torching of a 2 foot by 2 foot sample, it shows that you are getting a good correlation with an actual tank car. I thought that those torch fire tests were very conservative in that the heat was not allowed to travel away from the plate in any direction as it would within a tank car and therefore a tank car would show much lower wall temperatures than a torch fire test.

A.M. BIRK: You see that the curves indicate that the bare plate test and the empty tank test are very similar. I think that what they are saying is that by choosing a plate of that size you are accurately simulating a tank wall. But I think the torch itself at the torch fire test facility is a very conservative torch (Ed.Note: i.e. in the sense that it will result in severe fire). They are looking at a very severe fire impingement case. But it is not so much the flat plate that makes it conservative; it is the torch itself. It is a very severe torch.

C. GANNETT (U.S.DOT): In your scale testing, did your numbers agree with what is accepted as the railroad environment of 1600°F for 100 minutes for pool fire?

A.M. BIRK: I cannot tell you about the time. Basically what we looked at is a fully engulfing fire where the scale of the fire was large enough that thermo-radiation predominated, which is what is really happening in a large scale fire. We wanted to have a fire big enough to give 90% or whatever of thermo-radiation, and I would say yes, that that fire is giving you a standard engulfing fire. I have not calculated it, but that scale was large enough. The pool was three metres in diameter, extremely intense and with very good heat transfer rate. We were burning up all kinds of instruments.

C. GANNET (U.S.DOT): You did not run any full scale; you ran just one-fifth scale?

A.M. BIRK: Unfortunately yes, just one-fifth scale. I would love to do some full scale.

# HIGH PRODUCTIVITY TRAIN

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## ABSTRACT

The Association of American Railroads (AAR) initiated a major program in 1984 to promote the development of a new generation of trains [high productivity integral trains (HPIT)] to transport bulk and intermodal commodities. The Transportation Development Centre recognized the need for such railroad industry technological advances and supported the first phase of a program proposed by Transportation Technology Limited to develop new train system technology in response to the AAR challenge. Two distinct HPIT conceptual designs resulted from the work - a near term design and an advanced design.

The near term design (not discussed in this paper), has container and trailer variants that offer train operation savings of approximately 20% and that can be introduced into revenue service within two years. The cars are short, with two or three axles, having drawbars with slackless couplers. Each car supports one-half of two containers.

This paper deals with the advanced design. It offers origin to destination cost savings of 50% for intermodal freight, operational flexibility, and will require a four-year development and test program. The train arrangement consists primarily of monocoque car bodies to accomodate containers, distributed propulsion, a command module to control train operation and single axle radial trucks. This design is revolutionary, but the technology is largely available or near production status in other industrial applications.

# 1.0 HPIT ADVANCED DESIGN CONCEPT

## 1.1 BACKGROUND AND METHODOLOGY

The AAR challenge, a target of 50% reduction of cost of rail freight is not an idealistic requirement, but rather a statement of economic reality based on rail's continually declining market share (see Figure 1).

It became apparent that the evolutionary development of existing rail technology would lead to productivity improvements which, while significant, would fall short of the ambitious target. A 50% reduction would require a more fundamental and revolutionary overall system examination with significant advances in particular technologies.

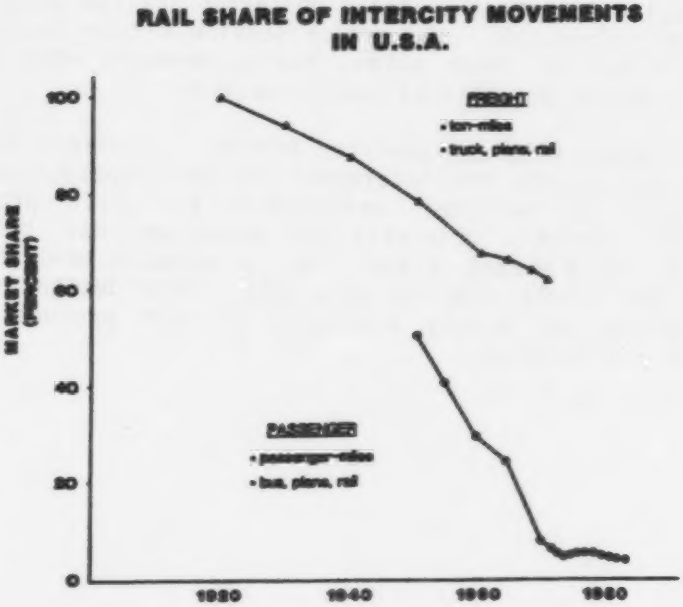


FIGURE 1: RAIL SHARE OF INTERCITY MOVEMENTS IN USA

Thus, TTL embarked on a conceptual design exercise responsive to the target objective. The advanced design assumed only the movement of bulk and mixed cargoes.

A cost analysis based on CIGGT industry data, considered a hypothetical trailer train operation between Toronto and Winnipeg and provided some illuminating observations. There are 13 major categories of cost, the largest single item being pick-up and delivery at 21%. Direct train operation costs are only 30% of the total, and intermodal yard operations account for 17% of the cost.

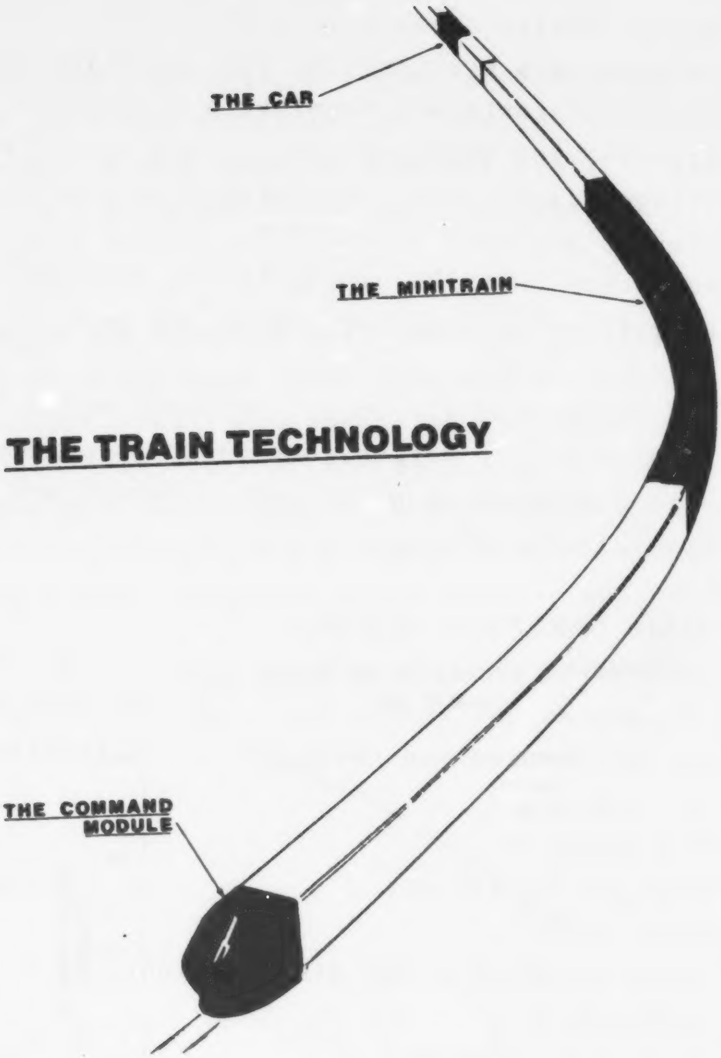
An analysis of the impact of fundamental factors reinforced the notion that improvement must occur across a broad range of cost elements and must, where possible, be deep.

## 1.2 TRAIN CONCEPTUAL DESIGN

The conceptual design applicable to general freight is illustrated and reviewed below, examining:

the body;
axle configuration;
axle sets;
power generation and distribution;
cargoes;
loading/unloading;
control of train;
braking; and,
operational considerations.

A view of the train and its major elements are shown below.


THE CAR
THE MINITRAIN
THE TRAIN TECHNOLOGY
THE COMMAND MODULE

GENERAL CONCEPT

### 1.2.1 The Body

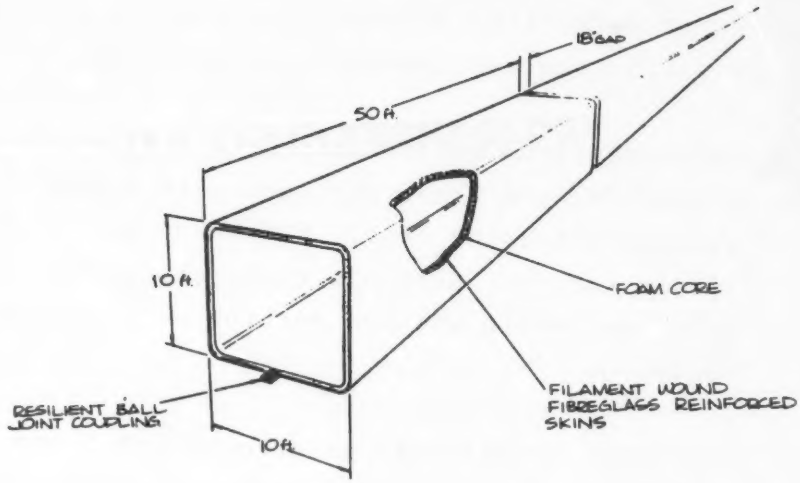
In a train with low draft and buff loads, maximum structural efficiency of the car is achieved with a short car and maximum structural depth. Thus, a monocoque (or semimonocoque) structure surrounding the cargo (but within Plate 'C' clearance) is dictated. The minimum length consistent with typical cargoes is about 50 feet, which would accommodate proposed container configurations. The body design was based on a load of 100,000 lb, including car plus cargo. Such a prismatic tube could be executed in a variety of materials, however, the most promising from a weight and cost perspective would be:

i) large aluminum extrusions, oriented lengthwise, closed for the floor and open with integral stringers for the rest. Bulkheads would be widely spaced. Such a structure would be welded by an automatic welding machine with multiple heads; or

ii) fibreglass reinforced plastic in inner and outer skins with a foam core. Such a structure would be filament wound in an automatic process (see Figure 8).

A filament wound structure would weigh approximately 5,000 lb. Other structures would be expected to be both heavier and more costly. Both technologies appear to be sufficiently developed for this application.

This closed structure with smooth outer skin would be expected to provide an aerodynamic drag coefficient less than 10% of existing configurations, regardless of cargo configuration or presence. The aerodynamic drag would be comparable to passenger coaches.



**THE CARBODY**

18" GAP
50 ft.
10 ft.
FOAM CORE
RESILIENT BALL JOINT COUPLING
FILAMENT WOUND FIBREGLASS REINFORCED SKINS
10 ft.

CARBODY

Aluminum, and especially fiberglass are characterized by low moduli of elasticity and have shown an ability to absorb significant energy in the buff loading case.

### 1.2.2 Axle Configuration

The selection of axle configuration is based on several criteria:

i) Axle Loading;

Rail wear and wheel wear depends on static axle loading and dynamic loading, which is, in part, a function of speed of operation and unsprung weight. For high speed operation, low axle loading is preferred. For mixed cargoes, the selection of maximum axle loading is not as simple as for bulk cargoes, because cargoes typically are limited by volume and maximum weight is rarely achieved. Based on information provided by CN and CP, a forty foot container/trailer is expected to carry a loading of 30,000 to 34,000 lb on average, rather than the maximum capability of approximately 57,000 lb.

ii) Number of Axles;

In general, it is desired from a maintenance, initial cost and drag perspective to minimize the number of axles. On the other hand, lower rated axle-sets provide lower equivalent inertia and additionally, because of their smaller diameter, permit lowering of the centre of gravity.

iii) Setting Out;

The preferred configuration is one in which a car may be set out, or in the case of damage or failure, be exchanged for a new car. Thus it is desirable that the car be self standing.

iv) Steering and Stability;

A configuration is preferred which provides accurate steering and dynamic stability to speeds higher than evisaged in service.

v) Weight;

In order to minimize weight per se, and unsprung weight in particular, a truckless configuration is preferred.

For the typical maximum and average cargo weights, and orientation toward speed and steering, the following configuration is selected. It provides two axles per car and can be set out if necessary. The maximum axle loading is less than 25 tons, and with a forty foot cargo may be on the average as low as 9 tons.

A 28 inch wheel is selected to provide a low centre of gravity.

The axles are individually mounted on the car at each end using resilient suspension, and can accommodate a 20° curve.

The long wheelbase will contribute to stability, and accurate steering is achieved by connecting the axle through a link to an adjacent body. This configuration is expected to require low maintenance, primarily because of the resilient mounting method. The major components are potentially off-the-shelf parts.

It is proposed that the inter-car connection be a ball joint, (in fact a resilient component to reduce wear) effectively slackless. The joint provides angular freedom in all directions, but provides vertical shear capability. This has the advantage of enabling load sharing between adjacent cars and axles, thus reducing rail wear.

Accurate steering is an important design feature because it has primary impact on rail wear (track maintenance) and wheel wear (car maintenance). Additionally, rolling resistance is reduced in curves.

Another potential benefit is lower noise, and therefore, in built-up areas, enhanced environmental acceptability.

### 1.2.3 Axle Sets

It is clear that dynamic loads play a major role in rail and wheel wear on tangent track. Thus, it is concluded that this phenomenon must be addressed inthe design of a high speed mixed cargo freight train. Here, we define speed as equivalent to existing passenger service, approximately 100 mph.

Train operation requires a trade-off among rail life, train speed and axle loading. Traditionally the compromise has led, for bulk trains, to an increased axle loading.

If dynamic loads were reduced it is seen that large productivity improvements could be achieved.

From the train perspective the physical variables involved are unsprung mass and mass distribution, wheel stiffness and damping. The principal concern is the quantitative value of the amplification factor in a multi degree of freedom dynamic system.

In this train concept one measure is to operate at low axle loadings to improve rail life at speed.

A side objective, of course, is the reduction of mass and equivalent mass due to rolling inertia.

Additionally, the dynamic load will be addressed in an HPIT development program. Historically, dynamic response has been addressed in transit applications, through the use of resilient wheels. In this field, however, the focus has been on noise transmissability rather than wear.

Promising avenues of development, building on transit experience, would be to alter the response of the wheelset through resilient wheels or alternative wheel materials (the tire remaining steel). Such materials are:

i) Aluminum: low modulus of elasticity, increased material damping; and,

ii) Kevlar: low modulus, significantly increased damping.

Modern manufacturing methods for reinforced plastic components such as filament winding and reaction injection moulding may eventually prove cost competitive with conventional manufacturing methods for standard steel wheels. The precise worth of potential benefits has not been established. It should be noted however, that for a typical bulk freight operation, the cost of roadway maintenance attributed to the operation of one axle set over a 200,000 mile lifetime (as derived from Canadian railway cost information) is of the order of $10,000.

Work in this area, that is, wheel/rail wear is considered important in the development of a high productivity train.

### 1.2.4 The Minitrain

A discussion of loading/unloading and distributed propulsion will be considered later. It became clear that if the train were broken into "n" equal minitrain units, certain advantages may accrue. For illustrative purposes the ten cars per minitrain was selected.

When the minitrain is independently powered it is feasible to remotely manoeuvre it from a tower through a radio link. Thus, all terminal operations can be performed centrally without a locomotive.

Further, certain cargoes which are now handled by boxcar and bulk carriers with direct spur lines can be handled by a minitrain. Using a plug-in controller and a two man crew, the minitrain can be used for direct pickup and delivery.

In general, if the subunit is small enough, it can be loaded by ultimate destination and trains assembled on the basis of destination. For example, it is reported that of the piggy back traffic from Toronto to Winnipeg, 70% go beyond Winnipeg.

The power unit size required decreases as minitrain size decreases. In the range of 1200 HP or less, it becomes feasible to sling the power package under the lead car of the minitrain, similar to a "Rail Diesel Car".

This configuration reduces the number of different cars required in a train and allows both front and rear loading/unloading.

Further, it becomes feasible to set out a minitrain, (which can be done easily) rather than a car.

### 1.2.5 General Discussion of Cargoes

From a larger perspective the issue to be dealt with is material handling. That is, we are concerned with the point to point movement of goods. Some proportion of the goods transfer will be intermodal, primarily truck/train. The trucking industry, in order to become more efficient over long distances has moved historically to larger and larger units of shipment. This trend is, to some extent, counter productive with respect to service level for a class of smaller shippers.

Thus, for example, the 50 foot, 80,000 lb container has been postulated. Nonetheless, the ability to handle a smaller unit load is a competitive advantage.

In general, the conventional equipment required and time required to lift (load) a twenty foot container is similar to that required to lift a fifty foot container, but in this train two twenty foot units may be handled almost as easily as one larger container.

It should be noted that some advantage accrues from the fact that while the AAR challenge postulates an integral train, the concept developed here offers the inherent benefits of not requiring the train to operate as an integral unit.

### 1.2.6 Loading/Unloading

The ideal loading/unloading scheme requires little time, inexpensive equipment, and the versatility to handle units of all sizes without penalty.

The most promising technology is air bearing. The working components of this system are the shoe and the track. The shoe consists of a length of wound resilient cellulose, wrapped with a thin plastic cover. The shoe fits in the rail, an aluminum extrusion approximately 5 inches wide with a concave upper surface. Low pressure air is fed into the cavity between the shoe and the track from the rail through small holes (see Figure 10).

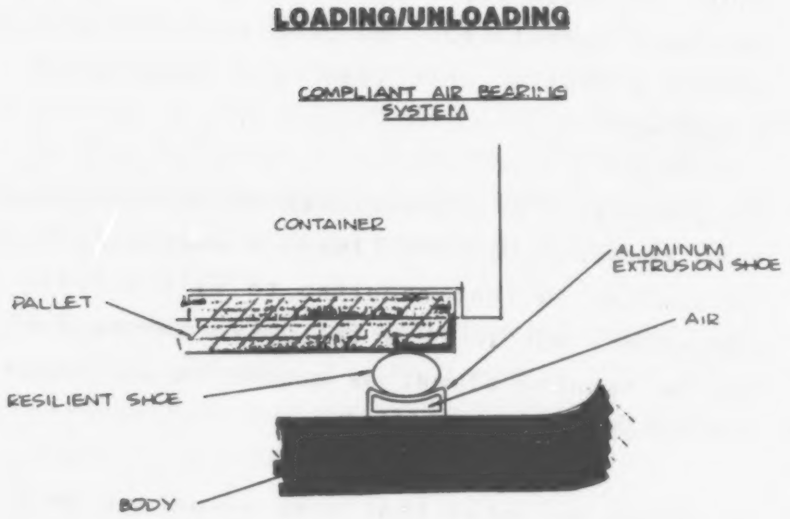

LOADING/UNLOADING
COMPLIANT AIR BEARING SYSTEM
CONTAINER
ALUMINUM EXTRUSION SHOE
PALLET
AIR
RESILIENT SHOE
BODY

FIGURE 10: AIR BEARING TECHNOLOGY

The combination provides guidance and levitation with low drag during loading.

It is proposed that shoes be placed on pallets which can support containers or on pallets carrying cargo. The rail would be placed in the cars, on loading/unloading docks and on a flatbed chassis for road transport.

For long continuous shoes, the coefficient of resistance is less than .02. Thus a typical container would require about 700 lb of thrust to move it.

A winch based on the train could readily accommodate the loading of ten cargo units simultaneously.

UTDC experience with this technology indicates that gaps can be readily crossed and outdoor operation is feasible. This application can be considered one of the least demanding of current applications.

There are many advantages to this technology compared with others.

i) Continuous Support of Cargo;

For existing containers, support is provided for the floor, thus alleviating the possibility of very heavy concentrated cargoes breaking through.

Cargo need not be carried in a container if it is not required for other reasons. A continuously supported pallet would weigh between 1,000 and 2,000 lb depending on design.

The pallet would be less expensive than a container and, compared to a typical 40' container at 8,000 lb, save at least 300 tons of tare per train (100 cargoes).

Should certain cargoes require enclosures, continuous support enables construction of a lightweight container, similarly saving on tare.

ii) Distributed Load;

In the detail design of the carbody, local loads must be accommodated. The rail distributes the load, resulting in an maximum pressure of about 7 psi (maximum loading on the floor). This pressure is, of course, tiny compared with wheels and permits a lighter weight carbody structure.

iii) Capital Cost:

The elements of the system are shoe, rail and air supply system. The shoe and rail are inexpensive. The cost of rail for a hundred car train would be modest. The air supply system for an extensive facility would be much less costly than the existing equipment.

The cycle times for a minitrain would be dictated by the time to disperse/assemble ten containers. Each set of additional spur lines enables one empty bay for quick unloading of ten cargo units and/or loading of one pre-assembled minitrain set of cargoes.

It should be recalled that loading/unloading applies only to those cargoes which apply to that destination. For example, based on the Canadian railways observation that 70% of the intermodal traffic from Toronto-Winnipeg has ultimate destinations beyond Winnipeg, for each 10 minitrains arriving in Winnipeg from Toronto, only 3 would enter the intermodal yard.

A large facility would be capable of cycling more than one train per hour.

It is believed that modest equipment capital requirements would enable handling of small or large volumes, with short train turnaround times.

iv) Customer Use of Air Bearing Material Handling System;

The system described herein has found some success in the movement and storage of goods within industrial plants. The potential exists to integrate the system with the customer's facility. The benefit is that the chassis need not remain at the shipper/consignee site. This would also enable direct delivery/pickup by minitrain where a spur line exists.

v) Cargo Protection:

The air bearing system shoe provides vertical and lateral suspension which enhances cargo protection against vibration and shock.

### 1.2.7 Propulsion

Typical power requirements for minitrain can be computed based on maximum and typical target cases.

| | Maximum | Typical |
|---|---|---|
| Car Weight | 20,000 | 10,000 |
| 50 ft container | 9,500 | |
| 40 ft pallet | | 1,000 |
| Maximum Cargo | 70,500 | |
| Typical Cargo | | 25,000 |
| | 100,000 lb | 36,000 lb |
| Ten Cars | | |
| 2.2 HP/ton | 1,100 HP | |
| 1.8 HP/ton | | 324 HP |

The actual power level selected will be based on realistic probability distributions for lading and form of cargo, computed for a complete train. It is expected that the resultant will be of the order of 400 HP per minitrain. It should also be noted that because of the significant impact of aerodynamic drag the lower HP/ton is more potent at speed. Grade climbing capability at speed compared with existing equipment is outstanding. At this level of power, 1.8 HP per ton, maximum train speeds of about 85 mph (on level, tangent track) are achieved.

The key implications of this power range are:

- size compatible with underfloor installation;

- Volume and weight compatible with unit removal by fork lift truck; and,
- selection from low cost, reliable, high performance truck engines.

It is important to select a power rating in a class of engine which is expected to respond to improvements over the next ten to twenty years. The 300 to 600 HP diesel engine class is in a competitive truck market and suitable for an array of military vehicles. For example, Cummins, a world leader in truck engine sales, is devoting significant effort to engine R&D in general, and to ceramic engines in particular. These developments would lead to more efficient engines and simpler non-liquid cooling.

Thus, for the system proposed, it is appropriate to select an existing diesel engine coupled to a standard alternator.

An example of such an engine is the Cummins NHHTC-350, a turbocharged four-stroke diesel providing 350 HP at 2100 rpm. Peak thermal efficiency of this engine is about 39%, very similar to existing locomotive engines. The weight is 2,580 lb.

The engine propulsion package consists of the following components.

- engine with fuel injectors, no auxiliaries;
- ac alternator;
- solid state rectifier;
- low voltage power supply;

- starting batteries;
- fuel tank and pumps (400 gal);
- logic controller;
- connection to DC bus;
- connection to control trainlines;
- health monitoring sensors; and,
- radiator and control.

It is proposed that the components can be packaged as a unit, approximately 2½ x 10 x 5 ft, and attached to the underfloor of the lead car using quick release fastenings.

This arrangement facilitates major maintenance by using a line replaceable unit strategy.

The distribution of tractive effort within the train can be achieved in many ways. Nonetheless, the advantages of distributed propulsion are greatest for tractive effort at each car. Draft loads, causing curve flanging and potential derailment, are eliminated. This factor becomes especially critical as the tare to gross weight ratio of a car decreases.

The benefits of dynamic braking are well known: no wear, rugged and reliable, infinite control and quick response with balanced braking in the train.

Fully distributed tractive effort requires a reliable inexpensive motor featuring low maintenance and rugged operation. With one motor per car unit, the size is approximately 25 KW. In the last few years significant strides have been made in power and control electronics.

Thus, the design incorporates one three phase ac electric motor per car, each with its own integrated variable voltage, variable frequency controller, supplied from a dc bus. This configuration overcomes potential wheel size differential problems and provides a small package suitable for a line replaceable unit approach. Because of the low adhesion demand and spin/slide control, wheels flats should be eliminated in normal dynamic braking.

### 1.2.8 Command Module

With distributed propulsion and tractive effort the power requirements for the control module diminish. Additionally, power is available, in general, from the dc bus in the minitrain. Thus it is proposed that the command module be a cab which can quickly attach to any minitrain. The cab will have retractable rubber and steel wheels for independent manoeuvering in the yard area, using small electric motors. The onboard equipment is limited to air conditioning, low voltage power conditioner, and batteries to supply power when the module is not attached to a minitrain.

The cab equipment is an integral part of the system operation and includes:

i) Autopilot:

It is proposed that the actual control of the train be done, in normal circumstances, by an autopilot. Updated periodically from a central system computer, the autopilot can execute the most efficient control algorithm with precision.

ii) End of Train Monitor:

Train integrity and end of train closed circuit television (CCTV) are continuously monitored and displayed in the cab.

iii) System Monitor:

The equipment displays local system status ahead and behind the train. The data includes train location, switch status, level crossing status, location, direction and speed of other traffic.

iv) Train Status, Train Control:

For each minitrain selected, operational information is displayed: engine performance, fuel, motor parameters, batteries. In addition health monitoring data is accumulated for later analysis or near term action.

v) Warning:

Emergency and action/attention conditions are displayed as a warning.

The approach selected minimizes, from a rolling stock perspective, the number of propulsion and axle configurations. It provides a minimum weight for the cab function and results in a relatively inexpensive structure.

The cab environment will be quiet, comfortable and air conditioned. Visibility is excellent, and aided by closed circuit television (CCTV).

One option which may be exercised is to provide a simple version of the command module which can be used for control of a minitrain for local delivery. For simple minitrain movements for maintenance, control is obtained by plugging in a portable control (hostling) panel.

### 1.2.9 Braking

It is expected that most of the normal braking will be provided by the propulsion system, dissipating the energy through brake resistors. The benefits of dynamic braking are well proven.

Two additional braking functions are required, parking brakes and emergency brakes. It is proposed to install a spring applied/electric release disc brake on one axle of each car.

In order to reduce the disc brake demand, thereby reducing wear and cost, it is proposed to use aerodynamic braking in emergency. These brakes are most effective at high speed where dynamic brakes provide low tractive effort and friction brakes experience high energy input. Deployable flaps on each car would provide a train brake rate of over .5 mph/sec at 85 mph.

It should be recalled that the train energy per unit lading is approximately one-half of an existing train; therefore, for the same train brake rate, the requirements for the braking system are halved.

## 1.3 SYSTEM OPERATION

### 1.3.1 Cargo Options

The minitrain can accommodate any container up to the design length, interior height and maximum weight of about 80,000 lb. The implications are:

i) the ability to handle 20 ft containers and thereby accommodate what are now considered part loads in a cost effective manner.

ii) the ability, through use of bin containers, to handle bulk cargo. Certain cargoes, now carried by boxcar could employ this approach.

Because the air bearing system can provide continuous support, the cargo structure can be designed to reduced criteria. The basic unit of carriage is likely to be a pallet. It can often be open or simply covered. Depending on design, a simple pallet would weigh between 1,000 to 2,000 lb. A lightweight non-stackable container would weigh less than 3,000 lb.

### 1.3.3 Control

It is proposed that overall operation of the system is controlled centrally. The information required is location and speed of each train and the status of switches. Based on the most recent data, target schedules are amended on a real time basis using optimization algorithms. Detailed train control decisions can be optimally computed and executed onboard. Achievement of this level of operational control is now feasible using ground based fibre-optic data links. Each minitrain contains a transponder with a unique identifier, read periodically through a wayside antenna. The intervals need not be less than one mile since interpolation is possible. Data flow to the train can be communicated in bursts at discrete intervals, using the same communication antenna system, and need not be continuous.

This level of communication and knowledge has been widely recognized as the next logical step for the railways, and is essential if the road is to be fully utilized.

### 1.3.4 Operations

The potential for increased market share, and commonality of equipment allows the opportunity to turn full circle from the concept of integral unit train to the concept of interchangeability of equipment, i.e., cars and cargoes.

The minitrain is like a car, separately addressable. The advantages compared with a typical car are:

i) unit size is large requiring fewer operations;
ii) no locomotives are required so the units can move on their own;

iii) the units can be remotely and individually controlled;
iv) for non-bulk cars, the units are easily loaded and unloaded;
v) accommodates a range of cargoes;
vi) the units are, of course, much more capable in terms of steering, resistance, control, etc; and,
vii) units are electronically identified and controlled.

If the bulk trains are fully compatible and operation is national in scope, then operation between centres is based on appropriate and frequent scheduled movement between two yards.

Train size is flexible. One command module and crew is required for each train, but no additional equipment is needed.

It is believed that the system, operated in this fashion can provide efficient, fast and reliable movement of a variety of cargoes, contributing to a healthy rail industry, and an efficient Canadian economy.

## 1.4 PERFORMANCE ASSESSMENT

To assess the impact of weight and aerodynamic improvements, the following trains were compared.

| | CONVENTIONAL | ADVANCED HPT |
|---|---|---|
| Locomotive Weight (lb) | 1,200,000 | - |
| BHP | 3,000 x 3 | 380 x 10 |
| | .85 | .85 |
| Lading (lb) | 126 x 27,000<br>= 3,402,000 | 100 x 27,000<br>= 2,700,000 |
| Car Weight (lb) | 63 x 65,000<br>= 4,095,000 | 100 x 10,000<br>= 1,000,000 |
| Tare (lb) | 126 x 8,000<br>= 1,008,000 | 100 x 1,000<br>= 100,000 |
| Train Weight (lb) | 9,705,000 | 3,800,000 |
| BHP/Ton | 1.855 | 2.000 |

TRAIN COMPARISON

| | | CONVENTIONAL | ADVANCED HPT |
|---|---|---|---|
| Resistance Components | Constant | 7,544 | 3,276 |
| | V (mph) | 97 | 38 |
| | $V^2$ (mph) | 6.88 | .77 |
| Lading (tons) | | 1,701 | 1,350 |
| Gross/Lading | | 2.853 | 1.407 |
| Speed at Max. Power | | 66 mph | 92 mph |
| Fuel Consumption Reduction At Steady Speed | | 45 mph | 68.1% |
| | | 55 mph | 71.3% |
| | | 65 mph | 73.6% |
| | (2) | 75 mph (1) | 75.4% |

TRAIN COMPARISON

(1) Note: 4 locomotives required.

(2) Based on equal ton-miles of lading.

| MANOEUVRES | TIME SAVED | FUEL SAVED |
|---|---|---|
| Accelerate 0-55 mph | 4.2% | 46% |
| Accelerate 45-55 mph | 3.2% | 61% |
| 1% Grade 2 Miles Long<br>Regain 55 mph | 7.5% | 58% |

TRAIN COMPARISON

## 1.5 BENEFIT ANALYSIS

The benefits reflect the objectives of the concept, addressing cost, speed and reliability. The cost analysis shows about a 50% reduction in cargo costs based on movement of mixed goods between Toronto and Winnipeg. The cost reductions are based on a number of assumptions.

1. direct cost reduction based on existing mode of operation;
2. cost reduction due to high train utilization typical of unit trains;
3. reductions related to increased speed, high availability and operating procedures;
4. reductions based on:
    - o increased market share;
    - o savings in through-terminal movements;
    - o share of direct delivery by train market; and,
    - o flexibility of command module operations.

Dispatch reliability is high and derived from:

1. high overall reliability through design - ac motors, solid state controls, no-wear joints;
2. health monitoring to detect incipient failure;

3. a "Line Replaceable Unit" (LRU) approach to major components; and

4. non-unit train operation.

For the route examined, the use of passenger train speeds, optimized train movements, reduced number of stops and quicker loading/unloading reduces cycle time from 42 to 36 hrs.

# DISCUSSION ON
# PRESENTATION BY D.N. FERRENCE

**K.C. TIKKANEN (Canadian Transport Commission):** What sort of a braking system would you see in this type of train?

**D.N. FERRENCE:** I propose essentially a braking system similar to the existing one. The differences are that first of all, we would see that dynamic braking would play a much larger role in this kind of train because of the distributed propulsion and we also propose the use of aerodynamic braking; that is, the use of flaps, which could be used at higher speeds and which would reduce considerably the requirements on the friction braking system. We don't know precisely what kind of friction braking system would be used, except that we have nearby electric power so that we would likely think in terms of discs rather than drums, perhaps cheap discs. Also, perhaps spring applied electric release - something that would fail in the correct direction but which could easily be released. We would cut the weight of the train in half and therefore would have a lot less energy to absorb in the braking system.

## 2.7 Technical Session #4 - Signalling and Communications

### Session Chairman

Mr. D.H. Walkington
Deputy Director, Signals & Communications
CP Rail
Montreal, Que.

# END OF TRAIN MONITORING

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## ABSTRACT

Economic pressure in the railroad industry has resulted in a search for ways to reduce operating costs. As a direct result, technology has been developed in the form of rear-of-train telemetry equipment. A Sense and Transmit Unit mounted on the trailing coupler of the last car conveys brake pipe air pressure and motion status to a Receiver Display Unit in the locomotive cab. A manually-initiated odometer in the locomotive provides a measurement of distance travelled past a point. Equipment embodying the capabilities outlined above has been in operational service in the United States since July, 1984, and has been successfully tested and demonstrated in Canada. A recent enhancement, developed for the Canadian market, incorporates the capability to apply emergency braking from the rear of the train, initiated in the locomotive cab.

# END OF TRAIN MONITORING

## I. RAILROAD TELEMETRY AND TRAIN AIR BRAKES

In early railroading before the development of automatic air brakes, the principal means of reducing train speed was through application of locomotive brakes. If more braking effort was required, crew members (brakemen) from the head end and the caboose (or brake van) moved along the train setting brakes on each car. Now, with automatic maintaining brake systems the engineer can set a precise amount of braking on every car in the train by using the brake lever in the locomotive.

With the increased effectiveness of automatic air brakes came complications. Correct operation of the brakes became a mandatory terminal test procedure (initial and intermediate terminal air brake tests) and mishandling of the brakes, especially on long trains, was added to the list of possible accident causes. Since the caboose air gauge and portable radio were added many years ago there has been nothing to improve the locomotive engineer's knowledge of what is happening in the brake system during train operations. This has now changed with the introduction of telemetry equipment which transmits measured brake pipe pressure at the trailing air hose of the last car to the locomotive, where it is continuously displayed. Now the engineer is able to monitor the brake pipe taper and can observe brake applications and releases as they reach the last car.

The display of tail-end brake pipe pressure readings in the locomotive has important benefits for railroad operations. The locomotive engineer knows the status of the brake pipe and brake applications immediately and continuously. Also, the intermediate terminal air brake test can be conducted using telemetry information in place of direct visual observations of the brake shoes on the last car, according to recent revisions of the power brake regulations by the United States Federal Railway Administration (FRA).

Telemetry equipment was originally designed with the simple objective of providing tail end brake pipe pressure readings in the locomotive cab. Soon more features were added: a motion detector to determine if the last car is moving or stopped, a highly visible marker (HVM) light as required by FRA regulations, and status indications for battery, pressure and communications. Some locomotive equipment also includes an odometer, stopped and started by the engineman, for measurement of distance travelled.

The locomotive is becoming the exclusive information and control centre of the train. This will lead to changes in railroad operations which are expected to produce long term economic benefits.

## II. FUNCTIONAL REQUIREMENTS OF TELEMETRY EQUIPMENT

Proper operation of the long and heavy tonnage trains typical in North America has become associated with the communication of certain information between the rear of the train and the locomotive. The most important information is brake pipe pressure at the rear of the train and, particularly, changes in that brake pipe pressure. The brake pipe, which runs the length of the train, serves not only to supply air to the brakes on each individual car but also provides the control whereby brakes are applied and released.

A train may not commence movement until the pressure at the rear car reaches a prescribed minimum value, typically 70 to 90 psi, which is read on a gauge in the caboose and reported to the locomotive engineer by a member of the crew using radio. At any time during movement of the train, if the caboose pressure gauge reading drops below a minimum threshold, it is the duty of the caboose crew to report this to the locomotive. Telemetering brake pipe pressure from the last car to the locomotive, where it is displayed to the engineman, means the information is available continuously in the location where it is required. Furthermore, the numeric value of that pressure compared with head-end brake pipe and brake cylinder pressure can be related by the locomotive engineer to the functions he is carrying out and the proper performance of his air brake system.

It is required by law that certain tests of brake pipe continuity be conducted both at the initial terminal (point of origin) and at each intermediate terminal where cars are either set out or picked up. The initial terminal test requires that a brake pipe reduction (brake application) be made and proper functioning of the brakes on each car be manually inspected. Subsequent intermediate tests require only that the brakes are confirmed to be "on" at the last car when the application is made. This in effect confirms continuity of the brake pipe through the train. Thus, the availability of the rear of train pressure on a display in the locomotive cab permits the intermediate terminal test to be conducted with great efficiency and minimal costly train delay. The engineer directly observes the reduction and restoration of pressure at the last car. Changes in the law governing air brake testing have recently been made in the USA to permit the use of telemetry in the intermediate air brake test.

The process of starting movement of a train, particularly with reference to a long and heavy train, is called "lifting" the train. This is an especially critical operation requiring careful application of locomotive power to stretch the couplers and start each car moving. If power is applied too abruptly then a high shock force develops in the train which can result in a pull-apart if the force exceeds the strength of the coupler knuckle. Once the entire train is moving locomotive power can be increased.

To assist the locomotive engineer, a motion sensor built into the rear of train equipment detects when the last car is moving or stopped. At start of motion, the locomotive display gives the direction of motion for approximately 10 seconds after which a different symbol indicating continuous motion appears. A separate symbol shows when the last car has stopped.

A confirmation of absence of motion when the train is stopped can be of equal importance to start of motion. One case has been reported where a cut of cars, including the last car with its telemetry unit, was set out while other work was being done by the locomotive. The engineer noticed that the "stopped" indication for his last car was no longer displayed and had the presence of mind to alert the yard crew who were able to apply handbrakes to the runaway cars and prevent an accident. Also, confirmation that the last car has ceased motion when the train is being brought to a stop provides useful assurance to the locomotive engineer that all is normal on his train.

It is a legal requirement in the USA for trains to display a rearward facing highly visible marker (HVM) light on the last car of a train during hours of darkness or poor visibility. The HVM is an integral part of the rear-of-train unit and its operation is controlled by a photocell which determines ambient light level. The state of the HVM (on/off) is telemetered to the locomotive for display, enabling the engineer to confirm his compliance with the regulations. Functional testing of the HVM is a legal requirement of the oncoming crew of any train. This can be costly in terminal delay, especially under cabooseless operation as a member of the head-end crew must be conveyed to the rear and then return after completing the test. Changes to this law are also being prepared whereby automatic testing of the HVM can be done using the telemetry equipment. This is done by turning the HVM on for a short period (10-30 seconds) each time the train starts moving. This gives ample opportunity for the locomotive engineer to notice and confirm the HVM "ON" indication in the cab.

The locomotive engineer frequently needs to know the location of the rear of the train relative to track fixtures such as switches, and wayside features such as at-grade road crossings. It is often necessary that the rear of the train draw clear of a particular switch to permit another train movement onto another track, or clear of a level crossing to allow road traffic free movement across the track.

This requirement is served by using a distance measuring odometer in the locomotive cab. Although not strictly speaking a part of the telemetry system it is frequently incorporated into the locomotive cab display unit. The odometer receives electrical impulse "counts" from a locomotive end-of-axle alternator commonly used to drive a speedometer. By counting pulses (at say, 60 pulses per wheel revolution) and using the known diameter of the wheel, distance travelled can be calculated. It is normally displayed in feet, and the indication is started and stopped by a pushbutton. Knowing the length of his train, the engineer initiates the counter when the locomotive is in the desired clear location. When one train length has been travelled, then the last car is at the desired clear location and the requirement has been met.

## III. DESCRIPTION OF THE TELEMETRY EQUIPMENT

### A. The System

The telemetry equipment comprises a sensing and transmitting unit (STU) mounted on the trailing coupler of the last car, and a receiving and display unit (RDU) located in the locomotive cab. The STU transmits blind (no receiver is incorporated, therefore there can be no confirmation that the data are received by the RDU), following logical rules as to when transmissions should be made. Transmissions are made upon a change in brake pipe pressure of 2 psi or more, upon occurrence of an "event" (marker light on/off change, motion sensor change) or at randomized one minute intervals if no changes occur.

All rear-of-train telemetry transmitters in North America operate on the same radio frequency, 457.9375 mHz. Each STU has a unique 5 digit identifier and this identification number (ID) is encoded into the data message. ID assignments are controlled industry-wide by the FRA and the Association of American Railroads (AAR) so that duplication of any ID is avoided. Each RDU has numeric switches in which is set the ID number of the STU on the rear. The RDU receives messages from any STU within range but will display information only from the STU whose number is selected by the switches. A high level of security coding in the messages prevents errors in ID decoding. Channel congestion might be predicted with all equipment operating on one channel, but the use of low power radio (2 watts UHF) and the FM capture effect assures that at least 20 equipment sets can operate in close proximity (5 miles) without noticable loss of communications throughput.

The AAR issued a document entitled "Guidelines, Considerations and Radio Frequency Specifications for Train Information Systems" in December 1984 (Issue 5) with the intention of completely defining system operation. The objective was to achieve interchangability between equipment from any manufacturer conforming with the document. This objective has been met successfully; today many railroads operate with "the AAR System" and interchangability of equipment between manufacturers has been successfully demonstrated. It is clearly in the interest of all railroads to conform with this "standard" as it involves absolutely no compromise in performance and opens the opportunity for procurement from several alternative sources.

### B. The Rear Unit

The rear unit or STU is mounted and locked on the trailing coupler of the last car of the train. Some are mounted in such a way that the coupler can be used for normal train operation; eg., for a pusher locomotive, others are not. The Units are connected to the trailing brake pipe hose and are turned on automatically by an air pressure switch when brake pipe pressure reaches approximately 5 psi. Rear units are battery powered and will operate between 60 and 450 hours on a fully charged battery. Programmable (micro- processor) logic controls the creation and transmission of message "packets" to the RDU. This logic includes such special features as automatic HVM testing. The data include digital pressure from a transducer, motion sensor and marker light status, and battery condition. A local digital display of air pressure is incorporated into the STU for reference by ground personnel installing and checking the equipment. To preserve batteries the rear unit shuts off automatically if brake pipe pressure is below 5 psig for 5 minutes.

### C. The Front Unit

The front unit or RDU is mounted in a viewable location in the locomotive cab and operates from the 72V DC electrical system. It incorporates an eight-character liquid crystal display and an audible alert. The alphanumeric information display comprises:

rear brake pipe pressure - up to 3 digits
last car motion - moving/stopped/direction
marker light status - on/off
STU battery state - ok/weak/fail

Warning messages and audible alerts are also provided for:

loss of radio continuity
low brake pipe pressure (below 45 psi)
no air (normal shut down)

Thumbwheel switches for entering the ID of the desired STU are located on the faceplate together with pushbuttons which start, stop and clear the distance measuring odometer.

### D. The Communications Link

For rear-of-train telemetry to be successful the communications equipment must be reliable and the radio link from rear to front of the train must give high throughput efficiency. Considering that the rear unit is mounted on the coupler and operates at low power (2 watts radiated) this requires a highly efficient data modem.

A synchronous binary FFSK modem operating at a 1200 bits per second data rate is used. The two frequencies used are 1200 Hz and 1800 Hz and frequency shifts are made at the zero crossings to achieve phase continuity.

Measured performance of the modem, which in DIGITAIR is implemented in software in an 8051 microprocessor, gives a message transaction success rate (for a 288 bit message including bit and frame sync) of 98% at an RF signal level of 0.18 u Volts (6 dB SINAD).

Error control is equally as important as message throughput, because the appearance of wrong information on the locomotive display will lead to the system information being ignored by the users. An 18 bit BCH code is used for message security, derived from the (63, 45) primitive. This code is capable of detecting up to 7 bits of random error and 18 bits of continuous burst error.

## IV. OPERATING EXPERIENCE WITH TELEMETRY

The operating history reported here is based primarily on the results of DIGITAIR, the system with which the author is most familiar. DIGITAIR was the first telemetry system to be accepted operationally by the railroads and it has continued to set the industry standard for performance. Other manufacturers now have equipment in operation whose performance approaches the levels described here.

Over a 15 month period from October 1983 to December 1984 a series of operational tests of DIGITAIR were conducted. These could properly be described as operational qualification tests. The railroads which participated ( a total of 15 in Canada, the USA, and Australia) were interested to learn if telemetry systems would function accurately and reliably; the equipment development engineers required the opportunity to confirm performance details and complete debugging. The radio link, which is crucial to system success, was the focal point of the testing.

A total of approximately 55,000 miles of operational use of DIGITAIR, and about 1 million radio transmissions over all types of terrain were logged. An aggregate throughput efficiency of more than 98% was recorded from these tests, based on individual message transactions. Since a loss of continuity is declared only after 3 or 5 (depending upon the protocol used) consecutive missed transactions, the operational availability of the system radio link was well in excess of 99%. In recent tests conducted using equipment selected at random by the railroad, this level of performance has been confirmed.

Accuracy of the brake pipe pressure measurement has been high because fully temperature compensated solid state technology is used. Typical accuracy is ± 1 psi and even at the temperature extremes of +70°C or -40°C the error rarely exceeds 2 psi on units selected at random for test.

In the United States, where telemetry has been operated on six railroads under a waiver permitting its use for intermediate terminal air brake tests, the FRA has closely monitored equipment availability statistics. It was reported in October 1985 that up to that time some 124,000 train starts had been observed and equipment availability averaged 98.7%. Availability was determined by installing the rear unit, putting it into operation and then ensuring that normal operation was successfully established with the locomotive cab unit.

At present there are approximately 2,000 sets of telemetry equipment operating in North America. More than 1,000 trains per day are operating without cabooses. Not all of these trains use telemetry equipment, but that percentage is increasing and it is expected that rear-of-train telemetry will be use on a majority of trains within 3 years.

The logic and radio portions of the system have performed exceptionally well in field service. The most frequent source of reported problems has related to mechanical damage to the coupler-mounted rear unit. This unit operates in a severe environment of high vibration and shock, temperature extremes and rough, unsympathetic handling. Shock loads approaching 20g have been measured under some operating conditions, and vibration loads in the 1-15 Hz region of 5g. Much has been learned about survivability of equipment in this service and improvements in equipment design are being phased in as problems are identified and resolved.

## V. REAR OF TRAIN BRAKING

### A. Functional Description

Another function available in modern train operation, which has not yet been mentioned, is the initiation of train emergency braking either upon radio request from the locomotive engineer or at any time when, in the judgement of the tail-end crew, this is necessary to preserve or restore safe operation. Incorporating this capability into the telemetry system reduces the time required to initiate braking and ensures that brakes are applied even if the tail-end crew cannot receive or respond to a radio request.

Some railroads, particularly those operating on high gradient trackage, have expressed a desire for telemetry equipment which incorporates the capability to initiate emergency braking at the rear of the train and the Canadian Transport Commission has requested that such equipment be tested and evaluated. As a result, a variant of DIGITAIR has been developed which provides the locomotive engineer with the capability to initiate rear of train emergency braking upon selection of an actuating switch in his cab.

Rear-of-Train Braking (RTB) requires two way communication capability so that the rear unit not only transmits data to the front but also receives the command to initiate braking. In addition to a radio receiver, the rear unit requires an air valve capable of triggering the emergency air dump valve in the last car. Once the car emergency valve is triggered the emergency release will propagate up the train, car by car, in the normal manner.

The RTB front unit requires a radio transmitter in addition to its receiver, and also an actuating switch. Furthermore, it is desirable that self-testing of the radio link from front to rear be done on a regular basis to ensure the link is available and advise the locomotive engineer should loss of the link occur.

The introduction of two way communications greatly complicates the system timing. This is particularly true considering that the rear unit is battery powered and therefore its receiver cannot remain on continuously; its duty cycle must be as low as possible commensurate with achieving the level of response required operationally. Many other significant design changes were required in the rear unit: antenna switching was added so the single antenna can be used for both transmitting and receiving, processors were upgraded to handle the additional functions, a solenoid-actuated trigger valve was added and a pressure-activated brake pipe venting valve was incorporated into the glad-hand connector. Further, both the radio transmitter and receiver were engineered to operate down to the specified low temperature of -45°C.

The front unit required an upgraded power supply to handle the additional load of a transmitter, as well as antenna switching, upgraded processors and additional control functions for the emergency brake command.

The RTB system has been designed to be compatible in its communications messages with the one way system. Therefore equipment can be mixed and each unit will operate to its capability. The protocol and format of the front-to-rear message is different from the rear-to-front, however. An extended bit synch transmission is used as a mark busy indication.

### B. Test Results

Prototype equipment has been built and a careful program of qualification testing and operational evaluation carried out. Particular attention has been given to cold weather operation. The air valve has been tested in extreme cold and with ice accumulation. Performance of each radio link and proper functioning of the logic has been tested both in train operation and in a cold chamber down to -45°C. In May 1986 an extensive field test was made, a cross-country trip from Vancouver to Halifax. Performance measurements were made at frequent intervals and operation under normal railroad conditions was observed. The equipment performed as designed and the test was an outstanding success. Further testing will be done to confirm performance and reliability, and a limited initial production run is being made.

## DISCUSSION ON
## PRESENTATION BY R.J. POMEROY

I.R. GRUNWELL (CN): Does the rear end transmitter transmit continuously to the head end, or is there a sending interval?

R.J. POMEROY: The rear end transmitter has a protection against the transmitter keying on continuously. It simply transmits on a schedule. If there is, for example, a change of motion or a change of more than 2 pounds brake pipe pressure, the unit will transmit this change. Otherwise there is one transmission every minute. The locomotive unit monitors the interval between receiving messages and will warn the locomotive engineer if the time interval is excessive. Excessive is usually defined as between three and five minutes. This time interval is a parameter that can be varied quite easily because the locomotive end is processor controlled as well. After an "excessive" period we put up a written warning in the cab that says "no com". There is also a specification that says you should flash all the information on the display if it is more than three minutes (or five minutes) old. It is the locomotive end that determines whether or not the link has broken down.

P.A. LAROSE (CANAC): What about the opposite situation in a congested yard where you have say, 10 or 15 of these units broadcasting at the same time. Is there a saturation level here?

R.J. POMEROY: It is a gentle degradation and I am glad you chose 10 and 15 as examples, because 18 is the level at which we start to see some degradation. There is a slight slow down in the time it takes for an event to get from the tail end to the head end. We have done experiments which confirm our calculations that at about the level of 18 units we will start to notice the presence of other units. It does not cause any errors or problems like that, but it does extend the time interval required. The low power of the transmitters, and the FM capture effect that operates on the receiver at the head end, effectively limits how many units can affect any given receiver. It is pretty difficult to get more than 18 trains all jammed into a rail yard so I think that it is very practical. It is something that operationally has never yet been tested because there is not enough equipment in service now to really know. We have to use our engineering judgment on this one and I really don't think that it is going to be a problem.

N.E. RUDBACK (TDC): Dick, you showed beautiful pictures of a peaceful coexistance with operating employees. How long is that likely to last? Would you or anyone else like to make a comment on that?

R.J. POMEROY: I am getting outside of my comfort zone now. It is a very hot topic in the U.S. right now. It is being negotiated with the Union. The first agreement permitted about 25% of trains to operate cabooseless. I think that has been increased on many railroads to 50%. Some railroads have negotiated separately from National labor agreements to increase the use of cabooseless trains. The economics of cabooseless train operation are very compelling, so there is a strong motivation for railroad operators to go that way, on through trains particularly. A train that is going to switch cars every few miles will probably always have a caboose on it, - it makes sense from lots of points of view. It really makes a lot of sense not to have a caboose on container trains, the high speed trains. The situation in Canada seems to be moving a little more slowly. There was a set of hearings; there were tests done, and there are still tests being done. I would not like to guess when some decision one way or the other is going to be made, but it is certainly being looked at here as well.

May I add that in concluding my presentation, I did not turn over the final page of my notes. I would therefore now like to acknowledge the assistance that we received from Transport Canada and TDC, in particular from Micha Avni, on development of the telemetry systems that I have described. I also acknowledge the assistance of both Canadian National and Canadian Pacific in defining and testing the rear of train braking feature. Thank you.

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# LIGHT EMITTING DIODE SIGNAL TECHNOLOGY

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## ABSTRACT

The paper begins with an explanation of the fundamental optical and visual properties of long-range wayside signals, and how TDC has been supporting technology to improve reliability and safety. The existing signals utilize incandescent lamps as the light source, interposing red, yellow or green filters by use of an electrically driven mechanism. The light emitting diode (LED) project set out to eliminate both lamp burnout and moving parts, through the use of high brightness LEDs of each colour, electronically switched.

After reviewing the current state of LED technology, advantages and disadvantages compared to incandescent lamps are discussed, and the research approach taken is explained. It is emphasized that the optical treatment of LEDs is different than for traditional point sources if maximum output is needed, and two approaches are shown. Complexities introduced by the qualitative nature of existing specifications are discussed, along with the method used for quantifying the results of visibility tests of the prototypes.

Optical characteristics of the prototype LED inserts for retrofitting existing signals delivered to TDC at the end of the project are discussed. They provide 800 meter range in bright sunlight, exceeding the minimum requirement but falling short of complete equivalence. Far greater range is attainable with red LEDs, but yellow and green lag because the individual devices are less bright. Also, the best green currently available is deficient in blue according to specifications, although tests by individuals with normal colour vision were satisfactory.

# LIGHT EMITTING DIODE SIGNAL TECHNOLOGY

## 1.0 INTRODUCTION

This paper describes innovative work being carried out in Canada to improve the visual components of rail signal systems. Since 1983, TDC has been supporting R&D on wayside signals and DAVIS has focussed on the application of solid-state light emitters to this system. Two desires have spurred this attention: that the safety of the signal system be increased, and that the substantial costs of maintenance be reduced.

This paper describes our progress, some of the problems encountered along the way, and where we believe the technology is going. Already, spinoffs of these projects are in or nearing service on Canadian roads.

## 2.0 EXISTING SIGNALS

Wayside signal units are narrow angle light projectors providing coloured indications to the engineer of the permission being granted to him to proceed past, and the range of speeds which he can use until the next signal is reached. Although the external housing is very robust, the internal mechanism is quite precise, consisting of a small tungsten filament lamp, mirror, lenses, colour filters and a rotary drive and contact mechanism. This design has evolved over many years, to the present time when the most usual maintenance is limited to periodic lamp replacement and occasional realignment of the inner (moving filter) assembly.

These signals, referred to as "searchlight" signals, display red, yellow or green aspects up to about one mile, depending on viewing conditions and whether or not a supplementary spreading lense is used. The source is modest, usually a 10 or 18 Watt lamp run under-voltage to extend its life. The system is moderately "fail-safe" in the sense that a dark signal is defined as "stop-and-proceed cautiously", and that loss of colour control power allows the mechanism to move the red filter into the light path by gravity. There are currently about 20,000 of these lights in service in Canada.

Since each filter subtracts all components of the initial white light except those desired, the emitted colour (which is more correctly referred to as chromaticity) depends on both the spectrum of the lamp and the filter. Filter glasses are rigidly specified such that light from a standard lamp will provide internationally recognized chromaticity. In actual use, however, lamps are run under-voltage, shifting output chromaticity towards yellow. Because of this, the Association of American Railroads (AAR) specifies minimum lamp voltage, which in turn limits the life-extension possible to about 2,000 hours (total). Since most signals are on continuously and dark signals cause train delays, lamps are regularly replaced prior to failure.

Outright failures of the colour changing mechanism, which could result in the wrong aspect being displayed, are apparently rare and therefore difficult to quantify. Such failures are possible, given the delicate nature of the moving parts, and the potential for disaster is so high, that an effort to avoid them appears worthwhile.

Finally, the optics of these signals reflect light beamed into the outer lense through the colour filter and back out. A good source of bright light is the locomotive headlight; when the signal lamp is operating, the colour may be diluted, but if it has failed this reflected "phantom" may be entirely erroneous.

## 3.0 LED TECHNOLOGY

Light emitting diodes (LEDs) are new sources of light which have appeared on the scene as semiconductor technology has advanced, and they share many of the same attributes: solid state, extreme life, efficient and rugged. They are usually encountered as small indicators used indoors, for example on car radios, stereos, computers etc. They convert electricity directly to light, without heating a metal to incandescence, and can be chemically doped to emit various colours without filters. (Some are encapsulated in dyed plastic for identification or contrast enhancement.)

Recent advances in materials research (mainly in Japan) have made far brighter LEDs available. When focussed properly, it is possible to create signals visible at long range in sunlight, with electronic switching of colour, using arrays of many LEDs. Because of the critical application, rail signals may benefit from this development.

When comparing LEDs to tungsten lamps/filters as signal sources, the following must be considered:

a) As converters of electrical energy to light, the best LEDs are far more efficient. Overall efficiency (or power use) will depend upon colour, drive circuit losses, etc. but is typically three times better.

b) Absolute brightness of the tungsten lamp cannot yet be approached economically using LEDs, as too many are needed. They should not be considered as replacements for more powerful signals - yet!

c) LEDs, especially when used in arrays, are area sources whereas most filament lamps approximate point sources. This is vital when considering optical systems, as virtually all designs and components (lenses, mirrors etc.) work properly only for point sources. On the other hand, this can be a virtue - the designer is not limited to conventional shapes or single colours.

d) Arrays of LEDs offer redundancy; the failure of one or a few does not extinguish the signal.

e) Phantoms are less of a problem, since LEDs do not derive their colour from filters.

f) An LED signal may cost more initially, but will have little or no maintenance.

g) LEDs replace the component of lowest reliability, the lamp, thus raising overall system reliability.

## 4.0 TDC SPONSORED LED PROJECTS

In 1983, the Transportation Development Centre, a research branch of Transport Canada, solicited proposals for development of improved mechanisms for searchlight signals, particularly aimed at reducing relamping and elimination of moving parts such as the filter disc. DAVIS responded with a project to determine the feasibility of LEDs for this application, intending to determine by calculation and laboratory experiment exactly what the requirements would be. The work was complicated by the scarcity of photometric information about the current signal, especially its field performance; almost all specifications concerned component parts (lamps, filters, etc.) assuming the traditional design.

DAVIS attacked the problem in the following areas:

- Measuring examples of good existing searchlights.
- Seeking sources of high-brightness LEDs.
- Developing optical concepts for LED arrays.
- Examining electrical drive options.
- Developing packaging designs for retrofit.
- Assembling and testing breadboard optics.

## 4.1 OPTICAL DESIGNS

Two designs emerged; the first, most suitable for retrofitting to existing signals, is shown in Figure 1 and partially simulates the wavefront conditions to the objective (large outer) lense that it expects from the traditional point source. The second, shown in Figure 2, received far less development because it occurred late in the project. This approach uses multiple small lenses, one for each LED, without needing a large overall lense. It can produce a narrower, brighter beam than the first type.

## 4.2 LEDs

From the many suppliers of LEDs, DAVIS procured samples of the highest brightness devices in red, yellow and green. Compromise was often necessary between luminance (brightness), beam angle and chromaticity (colour), however a preferred choice for each colour emerged. LED technology was (and still is) evolving; over the course of the project, maximum luminance available from a single device rose by 20 times!

## 4.3 RESULTS OF PHASE I

In reporting on the first phase, DAVIS concluded that the idea was feasible, as demonstrated by laboratory results, and recommended a second phase to produce prototypes for outdoor visual testing. It was acknowledged that not all problems were solved; in particular, yellow and green LEDs were far less bright so more would be needed (compared to red), and chromaticity of the greens was outside the AAR specification (insufficient blue). In light of technology advances it seemed reasonable to expect continued improvements to bring yellows and greens up to the same performance as red LEDs,which have been available longest. Having all other problems solved would then permit rapid introduction of the new signal.

## 4.4 PHASE II PROJECT

The second phase was begun in 1984 with the objective of producing prototype LED retrofits with a minimum range in full sunlight of 400 metres (10 seconds viewing time at 145 km/h. It was realized that existing signals exceed this range, but this is minimally sufficient for many applications. The project objective also included obtaining as good a green as possible, even if it did not yet fall within AAR standards.

Effort was also directed towards drive circuitry to translate the existing polarity logic into separate red, yellow and green switches, and to protecting the LEDs from over-voltage spikes and polarity reversal. Also, a formal re-evaluation of LED types was conducted just prior to manufacturing the prototypes, to take advantage of the latest improvements in colour and luminance.

## 4.5 PROTOTYPES

LED inserts for searchlights were fabricated as shown in Figure 3. They consisted of a substantial printed circuit holding upwards of 200 LEDs, a convex lense, internal housing and a mounting bracket adapted to the particular style of signal. Test equipment was designed to permit longrange visual comparison with an unmodified signal, to determine range.

As soon as visual tests were attempted, limitations to the AAR definition of range became apparent. This definition reads, "Range shall be the distance on a tangent at which, under bright sunlight conditions and with the sun at or near the zenith, the aspects are clear and distinct to a person with normal vision". Apart from the lack of definition of normal, the eye is very adaptable and thus poorly suited for absolute measurement, when one is trying to compare a light to a previous appearance. We found that almost imperceptible changes to the environmental light caused major changes in range estimation, and individual judgements were widely scattered.

To obtain some repeatability and constancy from range measurements, DAVIS devised a sequence of relative tests. An unmodified signal was set up as a standard, and equipped with mechanical attenuators allowing sufficient light to duplicate its visibility at maximum range, at a number of intermediate ranges (max. range is 1600 m.; attenuators for 400, 800 and

1200 m. were built). For each prototype, visual comparisons to the standard were made at the various distances. These proved quite repeatable and consistent over various observers and ambient light conditions.

Overall, an LED signal having better than 800 m. range was achieved. Despite adjusting the mix of LEDs in the array to compensate for differing luminances, red range was always greatest; ranges well in excess of 1600 m. (1 mi.) were usual. Thus it appears that a "full range" LED signal will be available when green and yellow luminanaces catch up with red.

## 4.6 GREEN CHROMATICITY

Any serious attempt to provide critical transportation signals must include definition and control of colour. This is especially needed if signals can be compared, when a shift might be interpreted as a different colour. The AAR standard now in use is derived from an international standard long in existence, which was developed to reduce the possibility of mistake by persons with two of the most common colour-recognition deficiencies. Although train engineers are screened for normal colour vision, the standard presumably was adopted as additional insurance.

As mentioned, presently available LEDs do not meet the specification for green, which has a marked blue tint, especially at close range. DAVIS used the closest available match, which to most observers appeared "more green" than the conventional signal at close range. When compared side-by-side in daylight at range, the two appeared identical; evidently the blue component of the filtered tungsten signal does not influence the eye at ranges over 30 meters. Hoping that this might avoid the need for an exact chromaticity match, DAVIS conducted observer tests at night (when the range of any signal is lengthened). The results were not as desired; at night, the conventional signal is markedly blue at all ranges.

Currently, although a visually distinct green LED is available it would not be accepted under today's standards. It is possible to contemplate a standard updated to suit LEDs, but it is more probable that LED manufacturers, realizing the market possibilities of, say, traffic signals, will continue to strive for a "proper" green and will eventually succeed.

## 4.7 TYPE 2 OPTICS

A promising alternative to adapting an LED array to point source optics was explored during this project, and is mentioned here because it appears to be useful in an important spinoff, the use of LEDs in grade crossing signals. Figure 4 shows a multiple LED array wherein each device is positioned behind a small positive lense such that all emit collimated (parallel) beams.

The advantage of this arrangement is that beam focus is much sharper, and the losses suffered by LEDs at the edges of the single lense array do not occur. Reduced beamspread results in higher brightness and longer range, or fewer LEDs to achieve the same range. Devices may be added until sufficient range is produced, colours may be mixed at will, and the physical shape need not be round. During the project, a red array with range in excess of 2000 meters was fabricated using about 30 high-brightness LEDs.

## 5.0 CURRENT STATUS

Upon completion of the contract in the fall of 1985, DAVIS delivered two prototypes of retrofit LED inserts, to fit the physical mounting constraints of the two major suppliers of searchlight signals. These are being used for visual tests and to demonstrate the concept. They are equipped with the best LEDs currently available, but have the limitations on range and green chromaticity previously mentioned.

DAVIS also delivered an unpackaged demonstration of concept tupe two, using 37 small glass lenses with a mixture of red, yellow and green LEDs behind them. A full searchlight signal would need a larger array at the present time, because of lower output yellows and greens, and the same limitations on chromaticity apply.

As spinoffs, DAVIS designed and now markets LED power indicators used by the railways to ensure that a loss of commercial hydro to wayside bungalows is noticed before the batteries are discharged. This replaces a high-brightness neon indicator, eliminating twice-yearly lamp replacement and false alarms, in addition to providing a more visible light.

DAVIS has also adapted LEDs to an all-red marker signal, which at the moment requires a complete but non-functional searchlight mechanism. We are currently exploring the costs and benefits of such an insert; since only red LEDs are needed, it requires low power and brings all the virtues of LEDS, such as extreme life and zero maintenance, into immediate use.

## 6.0 GRADE CROSSING RESEARCH

Recently accepted by TDC is an Unsolicited Proposal from DAVIS to apply LED technology to enhanced highway rail grade crossing lights. It is not a direct development from the searchlight work, but instead is a result of realizing that LEDs are capable of being made highly conspicuous by flashing at a fast rate, for example 10 times a second. Although it has long been appreciated that the human visual system is more sensitive at these rates, conventional lamps cannot be switched quickly enough (due to thermal inertia of the filament) and suffer accelerated aging when cycled.

This work is just beginning, and is initially concentrated on picking a combination of modulation types and rates, and possibly a colour change, to stand out most clearly against various backgrounds. This will be followed by production of prototypes that will allow observer tests in controlled circumstances at selected crossings. Only after scientific evidence of increased effectiveness is available will this application be considered for installation.

## Acknowledgements

****************

Many individuals freely shared their experience with us on this project. In particular, Mr. Wayne Rowan of TDC has been an organizer of priceless assistance. Within CN, Messrs. Earl Chapman and Bob Field provided help and critique at every turn. From Carleton University, Dr. Brian Tansley of the Psychology Department provided insight into the human visual process and assistance with photometry problems. Mr. Ron Maughan kept our steering committee on the straight and narrow despite us, and many others contributed as we proceeded.

## References

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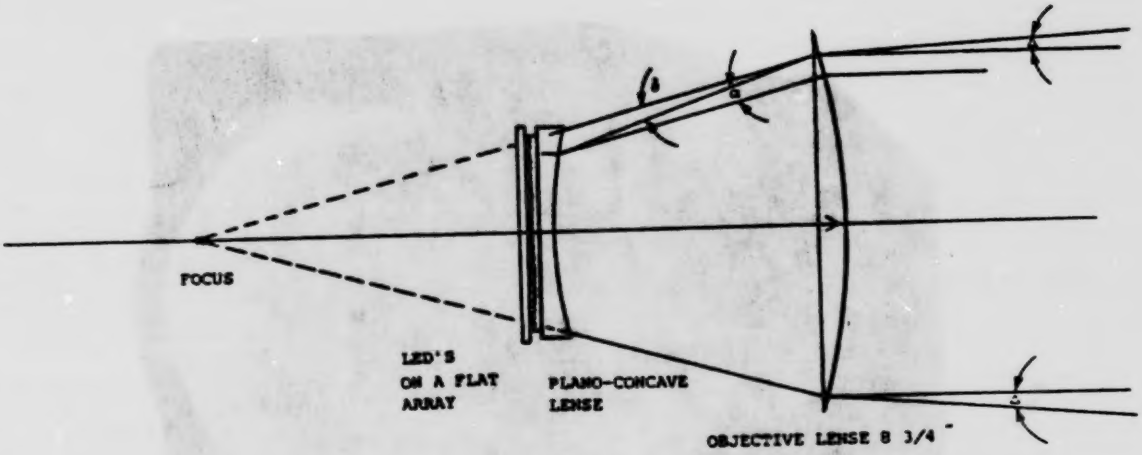
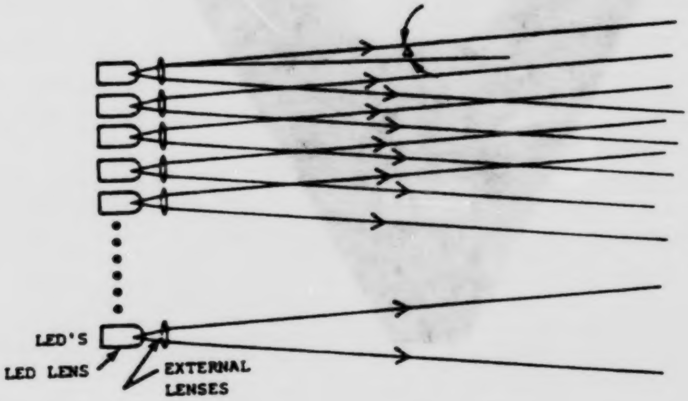
Tansley, Lougheed, Chapman, "Railway Visual Signals: Technologies Old and New", paper presented at the Twenty-fifth Annual Meeting, Association of American Railroads, Communications and Signals Division, Chicago, September 1985.


FOCUS
LED'S
ON A FLAT
ARRAY
PLANO-CONCAVE
LENSE
OBJECTIVE LENSE 8 3/4"

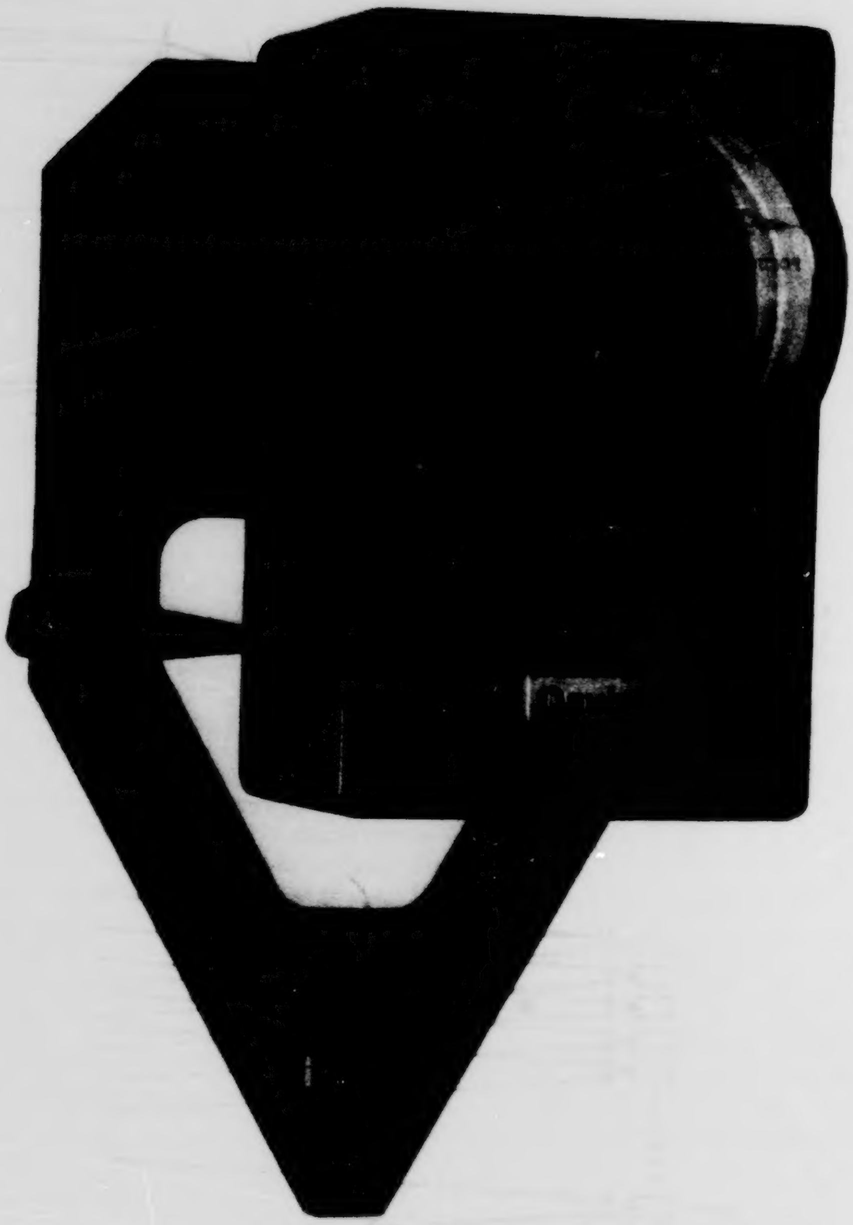
$\alpha$ IS THE DISPERSION ANGLE OF THE LED'S
$\Delta$ IS ONE HALF OF THE COLLIMATED BEAM ANGLE (2°)
$f$ IS THE FOCAL LENGTH OF THE OBJECTIVE LENS

FIGURE 1


LED'S
LED LENS
EXTERNAL
LENSES

**CONCEPT 3: INDIVIDUAL EXTERNAL LENSES**

FIGURE 2



TYPE 1 - LED ARRAY SEARCHLIGHT

FIGURE 3

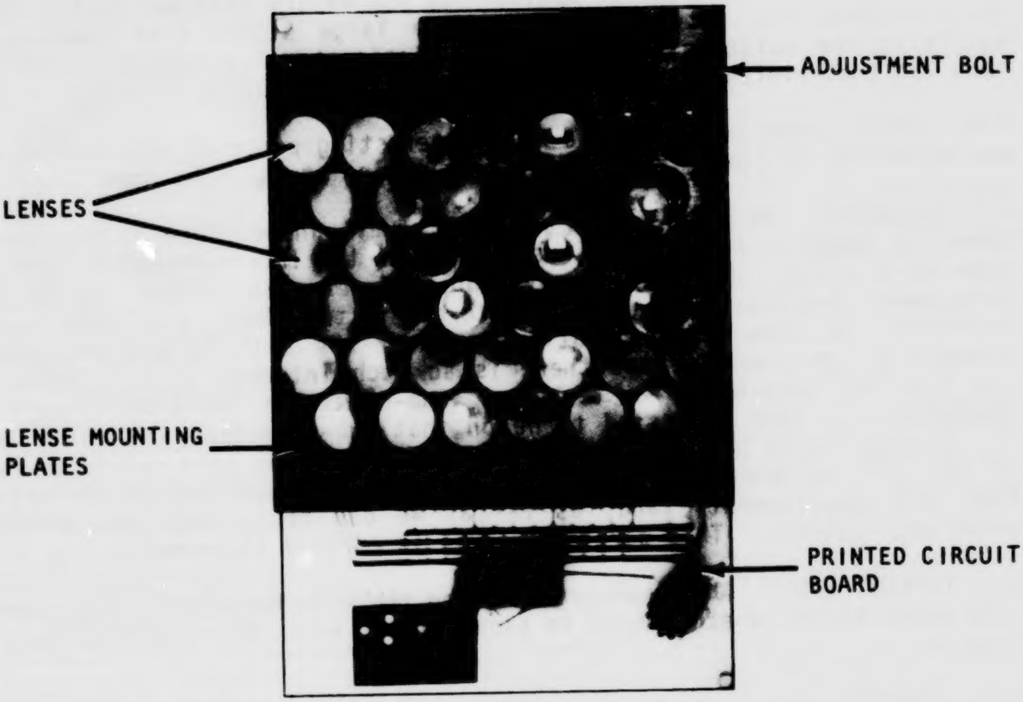

ADJUSTMENT BOLT
LENSES
LENSE MOUNTING PLATES
PRINTED CIRCUIT BOARD

FIGURE 4 TYPE II ARRAY

## DISCUSSION ON
## PRESENTATION BY J.H. LOUGHEED

UNIDENTIFIED DELEGATE; Do you foresee difficulty with (inaudible)?

J.H. LOUGHEED: The question was whether there was difficulty in alignment, I guess in a normal situation. No. What I was referring to was in developing these two types of optics. If you expand this out to include the three colors, you get physically a very large signal that does not fit easily in the existing housing. The existing housing has an 8-3/8" outer lens and that limits this kind of approach as a retrofit.

P.A. LAROSE (CANAC): This is a very interesting piece of engineering and I was wondering if Canada is the only one looking at it right now?

J.H. LOUGHEED: We hope so; we are pretty well ahead. One of our Steering Committee members, Dr. Brian Tansley sits on the International Illumination Commission (CIE). They meet every couple of years in Geneva. He was there this summer and there was a lot of interest in this topic expressed by other countries and other transportation systems. He sits on a Transportation Signalling Sub-Committee and there is so much interest in this topic that the CIE is sponsoring a technical Sub-Committee on LED signals and standards. I have requested to be on that Sub-Committee. I think Canada has an opportunity here to take a leading role in this area, where as far as we can tell, we are well ahead. The Japanese, as suppliers of the devices, have some developments, and, as far as we can tell, they are developing other applications. This particular area is ours at the moment.

R.J. POMEROY (DSL): Jim, have you checked the high brightness LEDs that you have used, to see whether they in fact put out what the manufacturers claim they do?

J.H. LOUGHEED: In a rough way, yes we have. One of the confounding things about measuring the output of the LEDs is the fairly wide scatter in product when you get it. You really have to do a spherical integration measurement and photometric units are particularly abysmal. They are really terrible. I certainly would agree with you in that area. You get situations where you have 5 or 6 suppliers, all quoting different measurements: candella, lumens, beam candle power, effective beam candle power, etc. The LEDs appear to be doing what they are supposed to do. Our basis really is visual tests. We feel that for the work we are doing, the most valid thing is to get out and see what it looks like in bright sunlight. It is not only the LED that is involved; we have lenses and alignments and all manner of other things. The peak brightness that is quoted for LEDs these days is 2 to 3,000 milli-candella and they do appear to be capable of reaching that.

R.J. POMEROY: I am glad to hear that you find those units a little bit formidable as well.

J.H. LOUGHEED: Well I have been coping with them for 20 odd years since student days and they are still rough.

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[illegible]

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[illegible]

# CONTAINER TERMINAL SIMULATION MODEL

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## ABSTRACT

The Container Terminal Simulation is a computer simulation of the major operations in an inland container terminal: inbound train arrivals and unloading, outbound train departures and loading, storage of containers arriving by train or by truck, customer pick-up of containers. The model consists of a batch simulation and a graphical postprocessor. The simulation evaluates plant designs, equipment trade-offs and yard operating policies. The model was used in the design of the Montreal container facility and is currently being used to assess the effect that changes in traffic levels would have on yard operations for the container facilities in both Toronto and Montreal.

# CONTAINER TERMINAL SIMULATION MODEL

## SUMMARY

Intermodal movement of goods over road and rail has become an increasingly attractive method of transportation in recent years. At CN, the increased workload has put a great strain on the existing plant and equipment. Improvements to container terminals involve large capital expenditures. Therefore, each alternative must be carefully evaluated before a final decision is made. A computer simulation is an excellent way of analysing and comparing design alternatives.

The Container Terminal Model (CTM) is a computer simulation of the major operations in an inland container yard. It was developed by Canadian National Railways' Department of Operations Research and Industrial Engineering and partially funded by the Transportation Development Centre (TDC) of Transport Canada.

The model has been developed to aid engineers and transportation planning analysts in the design of new container terminals and in the modification of existing ones. The model consists of two parts: a computer simulation of the intermodal terminal operations, and a graphical postprocessor.

The simulation can evaluate various plant layouts, equipment trade-offs and yard operating policies. The results of the simulation can then be graphically replayed by the postprocessor, animating the major operations in the terminal. Animation also makes it much easier to validate the logic of the simulation model. More importantly, the user can easily understand the model's logic, assumptions, and results.

A video presentation of the CTM is available from the TDC. This is an effective way to describe the model's features to interested parties. The video focuses primarily on the animated replay of the graphical post-processor.

# 1. INTRODUCTION

In Canada, the transportation of goods in containers and trailers forms a significant portion of the total domestic and international traffic. Intermodal movement, where the long haul is over rail, is expected to become increasingly attractive compared to a straight highway haul as energy costs continue to climb. In such a move, the container or trailer passes through at least two terminals where it switches between rail and another mode such as ship or highway. It is important, therefore, to design intermodal terminals with the objective of reducing resource requirements and decreasing the time spent within the terminal, so as to make rail transportation even more cost efficient.

The design of terminals and analysis of equipment requirements has, in the past, been accomplished through manual simulation. However, a computer simulation improves the quality of the analysis by encompassing more detail than is feasible in a manual version, enabling a greater number of alternatives to be examined within a reasonable time span. The wealth of detail resulting from such a computer simulation must be presented in a concise and easily understandable fashion.

CN Rail's Operations Research group, in cooperation with the Transportation Development Centre (TDC) of Transport Canada, has developed a computer simulation of inland container terminals, which incorporates computer graphics. The Container Terminal Model (CTM) can be used to test terminal design alternatives and changes in the operating procedures.

The model consists of a batch computer simulation, and an animated replay. The simulation is parameter-driven and the resulting log of events can be transmitted to a microcomputer where each event can be displayed on a graphics screen.

# 2. THE SIMULATION MODEL

## 2.1 Hardware/Software Requirements

The simulation model was developed on an IBM S/370 series machine with a TSO/SPF system. The model and the output reports are written in SIMSCRIPT II.5, a powerful modelling language. CN used the most recent version of the IBM compiler, V9.3, for model development.

The information required to run the simulation is entered at a computer terminal by means of formatted screens. Statistical Analysis Systems Inc. software (SAS and SAS/FSP) was used to design the formatted screen and to write the model preprocessor. If the model is being run on a system where SAS is not available, the data may be entered directly onto a sequential data file which can be read by the SIMSCRIPT program.

## 2.2 Inputs

There are four input data files, each of which can be edited separately. They are:

1. Plant layout and system parameters
   - duration of simulation, gathering of statistics, level of detail in the output
   - storage capacity and characteristics
   - gate processing time
   - average truck speed and flatcar length per TEU (twenty-foot equivalent unit)
   - positions of each gate, storage and track given in coordinates on a global grid of the yard layout.

2. Machine definitions
   - characteristics of the machine(s)
   - restrictions on its use
   - times to complete certain activities
   - shift duration and break schedules.

3. Train schedules
   - inbound and outbound trains
   - mean number of containers
   - assigned track
   - train arrival, departure, cut-off times
   - destination block data for outbound trains
   - number of corresponding empirical distribution.

4. Empirical distributions
   - arrival time in yard for outbound containers
   - customer pickup day for inbound containers
   - daily arrival pattern of inbound container pickup
   - train configuration (types of containers aboard)
   - empty container arrivals and departures in yard.

## 2.3 Simulation

The CTM simulates the following major operations in a terminal:

- train arrivals and departures;
- the storage of containers arriving by train or through the gate;
- customer pickup of inbound or empty containers;
- the unloading of inbound trains;
- the loading of outbound trains.

The following yard resources are modelled in the CTM:

1. Gate
   - processes paperwork for each container entering and leaving the yard;
   - hours and days of operation can be specified;
   - can have multiple servers at the gate.

2. Tracks
   - divided into spots to accommodate the flatcar space required for each container and adjacent trackside space.

3. Storage
   - multi-level areas for storing containers;
   - containers can be grouped by size, load vs. empty, and IMPEX vs. domestic;
   - each storage is divided into spots uniquely defined by row, column, and stack height.

4. Machines
   - used to load/unload containers from storages/trains/chassis and to move containers within the yard;
   - can be assigned to specific work areas, shifts, and types of work;
   - can be either a front or side loader, or a gantry crane.

A container arrives at an inland container terminal either by train or by truck. The train could have originated at another inland terminal or at a port terminal where the containers arrived by ship. Containers arriving by truck will either be sent out on an outbound train or stored in one of the on-site storage stacks.

The container cars arriving by train have previously been switched at the terminal's parent rail yard. One or more lifting machines are assigned to unload all the containers. They are removed from the flatcars, one by one, and placed in the appropriate storage area or directly on a chassis.

Containers arriving by truck pass through the terminal gate where their paperwork is processed. The driver then proceeds to the assigned yard destination, either the track (if the container is departing on an outbound train) or to storage (if the container is empty). The container is removed from the truck chassis and positioned by a lifting machine.

Containers leave the yard either by rail or by road. The containers which have been loaded onto flatcars will leave the yard when the track is pulled. The flatcars will pass through the parent yard where they may be switched onto a larger train. Containers that arrived by train leave the terminal by truck. Drivers from the container lines or the railways go to the appropriate storage area where they are met by a lifting machine. The lifter removes the container from its place in the storage stacks (which could involve the movement of other containers stacked on top of it) and places it on the truck chassis. The driver proceeds to the gate to sign release forms. Drivers may also arrive to pick up empty containers stored in the terminal's long term storage.

The CTM does not include such detail as the tracing of a container's whereabouts after it leaves the terminal, or the switching required to separate the intermodal flatcars from a larger train.

One of the assumptions in the simulation is that there will always be sufficient flatcars to handle all the containers arriving and departing by train. Therefore, questions of flatcar allocation and hitch utilization are beyond the scope of the model.

## 2.4 Simulation Output

The Container Terminal Model calculates many terminal performance indicators during a simulation run. Some of the statistics generated include:

- customer delays at gate
- gate queue length
- gate interarrival times
- track utilization
- storage utilization
- container traffic statistics
- customer service delays
- train load/unload times
- machine utilization
- track allocation plot.

One of the outputs of each simulation run is an event log of the simulation which can be transferred to a microcomputer for an animated replay of the run (See Chapter 3).

# 3. THE GRAPHICAL POSTPROCESSOR

## 3.1 Hardware/Software Requirements

The following equipment is used to run the graphical postprocessor:

A) Intel microcomputer - model 330A
B) Raster Technologies Model ONE/20 graphics display controller
C) 11" x 11" digitizer tablet with cursor (mouse)
D) 13" high resolution colour monitor (CRT) (512 x 512 pixels)
E) Standard CRT terminal.

All programs on the Intel computer run under the XENIX operating system. The programs are written in the language "C".

The logfile which is produced by the simulation is passed down to the Intel by use of XENIX system routines. It is possible to store several different logfiles on the computer at the same time.

## 3.2 Set Up for Replay

At start-up, all the available logfiles are displayed on the screen menu. A digitizing mouse is used to enter all commands, replacing a standard keyboard. The function of each button on the mouse is displayed on the screen for easy reference.

When a yard layout is to be used for the first time, the paths equipment and trucks follow through the yard must be adjusted to more accurately display the traffic routes used in the container terminal. These paths are initially displayed as straight lines connecting all objects in the yard and can be modified using the mouse. This needs to be done only once for each yard layout being tested.

Before the replay can begin, the user must also set the speed of replay and the maximum running time of the display.

### 3.3 Running a Replay

After the user has selected the desired LOGFILE, a schematic of the yard is drawn on the screen, showing the gate house, tracks, storage areas, containers and machines. At the bottom of the screen are indicators of the current simulation time and time limit for the run. Under standard magnification other information on the current speed setting, last command entered and the function of each button on the mouse are displayed beneath the time limit line.

The user has several options available when replaying a simulation run. The events can either be displayed one by one, or in continuous mode with an adjustable speed. There is a fast forward command which enables the replay to skip forward (at 10 times normal speed) to a specified time. It is also possible to zoom in on any area of the screen, with up to 8 times normal magnification.

The perimeter of each storage area is represented by a blue rectangle. If the storage contains containers they are drawn inside. Information as to container size, stacking height, place of origin and load status can be obtained from the way a container is drawn within the storage.

Horizontal yellow lines represent tracks. When a cut of flatcars is placed on a track, the cars are indicated by a purple line over the yellow track line. The train name is shown underneath the first flat car from the left. Front loaders are drawn as white squares with the number of the loader written inside. Gantry cranes are shown as vertical blue bars over the track and adjacent storage area. The gate house is the solid green square with the red roof.

Front loaders and gantry cranes can pick up or place containers on trucks, flat cars and storage areas. To represent the loader positioning itself and to identify which container it is working on, the container blinks while the operation is in progress. Containers appear attached to the lifting machines and trucks when they are being carried by them. The machines and trucks move about the yard on the paths indicated by the user. When a container and/or truck leaves the yard, it disappears from the screen.

When the replay is started, messages appear at the bottom of the screen indicating which event will occur next. The associated object will move on the screen and the current simulation time shown at the bottom of the screen will increase. This process will continue until the time limit is reached or the user stops the replay.

# 4. MODEL VERIFICATION, VALIDATION AND APPLICATIONS

## 4.1 Model Verification

Verification of a simulation model involves testing the individual components of the model to ensure that each part works as we assume it does. This contrasts with model validation, which tests the entire model to see if its results resemble the real world system.

The CTM program was extensively tested using sample data sets and different random number generators. The data sets were set up to focus individually on the different model components (e.g. train loading and unloading, empty container handling). These tests allowed errors in the program and in the model logic to be traced and corrected. Various enhancements were made to the model as a result of the verification.

The graphical postprocessor proved to be a valuable tool in model verification, especially on illustrating event sequencing problems.

## 4.2 Validation

The purpose of validation is to ensure that the simulation model behaves in a similar manner to a real yard. The container terminal selected for the test was Conport, in Toronto.

In order to describe and measure actual operations at Conport, three sources of data were used. In chronological sequence these are:

(a) Yard cards for August and September, 1983. These punched computer cards were used up to January 1, 1984 to control the inventory of containers in the yard and to provide a record of containers passing through the yard. For each container arrival at the yard, a card is produced which includes such data as: arrival and departure times, load or empty condition, origin and destination stations, and size of container.

(b) Sample week of December 5-9, 1983. A team of Industrial Engineering personnel visited Conport and collected data on operations during that week. Included were traffic levels in and out on trains and at the gate, yard inventory levels, hand cards showing detailed lift machine tasks and shifts, machine downtime records, yard layout, gate operations, track assignments and other operational details.

(c) Time studies. During March and April of 1984 time studies were conducted on lift machine operations, and on truck movements and waiting times within the yard.

The following table lists the computer simulation input data items, and indicates for each which of the above three data sources was used.

Table 1 Sources of Simulation Input Data

| | (a) | (b) | (c) |
|---|---|---|---|
| Track definition | | * | |
| Gate definition | | * | * |
| Storage area definition and boundaries | | * | |
| Machine shift definition | | * | |
| Machine activity times | | | * |
| Machine assignments | | * | |
| Outbound/Inbound train definition | | * | |
| Inbound train distribution - customer arrival times | * | | |
| Daily customer arrival distribution | * | | |
| Outbound train distribution - container arrival times | * | | |
| Empty container distribution | * | * | |

The computer simulation was run with traffic levels and yard resources closely matching actual levels of the sample week. Output measures from the computer run were compared to expected results based on the input data. The following table summarizes the comparisons.

Table 2 Validation Results

| Statistic Measured | Simulation Results Compared to Expected Results |
|---|---|
| Customer delay at gate | -3% |
| Gate traffic level | +1% |
| Containers arriving by train | +1% |
| Containers departing by train | -1% |
| Contents of loaded container storage | -2% |
| Contents of empty container storage | +3% |
| Loading machine utilization | +1% |
| Machine average movement distance | +4% |

One other important measurement is customer delay in the yard waiting for service by a lifting machine. Some measurements of customer delay were made after the sample week. Because traffic levels and number of machines in service were different from the sample week the results are not directly comparable. An adjustment was made to the observations to enable them to be used to make a rough comparison between actual and simulated customer delay. We feel that the simulation results are within 3 minutes of the probable actual average delay during the sample week.

Taken as a whole, the simulation's results are very close to those expected. We conclude that the simulation model adequately represents the operations of a real container terminal.

### 4.3 Applications

As a first test of the Container Terminal model, a trial application was performed. Its objective was to determine how many additional operating lift machines would be required to handle a 25% increase in traffic levels. Customer delay must be no greater than that for the base level of traffic and lift machines.

The base run for the application was the validation run. All traffic levels were increased by 25%. Three runs were done with different numbers of lift machines: first, with the number unchanged from the base run; second, with one additional machine operating for three shifts; and finally, with a second additional machine operating only for the day shift (0800 to 1600 hours).

Although we were not studying gate resources, the number of servers there was increased for most of the day. This was done to prevent a large queue build-up which would affect the rate of container entry into the yard.

The following table shows the levels of resources for the base run, and for the three application runs:

Table 3 Level of Yard Resources in Trials

**GATE**

| Time of Day | Base Run | Application Runs | % Increase |
|---|---|---|---|
| 00:00 to 06:00 | 1 | 1 | 0 |
| 06:00 to 07:00 | 1 | 2 | 100% |
| 07:00 to 08:00 | 2 | 2 | 0 |
| 08:00 to 12:00 | 2 | 3 | 50% |
| 12:00 to 13:00 | 2 | 4 | 100% |
| 13:00 to 16:00 | 3 | 4 | 33% |
| 16:00 to 18:00 | 2 | 3 | 50% |
| 18:00 to 20:00 | 2 | 2 | 0 |
| 20:00 to 24:00 | 1 | 1 | 0 |

**LIFTING MACHINES**

| Time of Day | Base Run & Run # 1 | Run # 2 | Run # 3 |
|---|---|---|---|
| 00:00 to 08:00 | 3 | 4 (+33%) | 4 (+33%) |
| 08:00 to 16:00 | 6 | 7 (+17%) | 8 (+33%) |
| 16:00 to 24:00 | 4 | 5 (+25%) | 5 (+25%) |

The following table shows some comparative measures from the simulation runs. In each case, the comparison is made to the base run (the run used to validate the model). The measures selected are those which are affected by the number of loading machines in operation.

Table 4 Comparisons to Base Case

| Statistic Measured | Run # 1 | Run # 2 | Run # 3 |
|---|---|---|---|
| Average Customer Delay | +69% | +23% | -31% |
| Containers Unloaded | +25% | +25% | +25% |
| Containers Loaded | +18% | +22% | +25% |
| Machine Utilization | +17% | 0% | -3% |
| Machine Travel Distance per Container | -10% | 0% | +2% |

It is obvious that the 25% traffic increase in Run # 1 degraded customer service, and affected the loading of outbound containers. There was insufficient loading machine capability at peak demand periods to complete the loading before pull time. As a result, the number of outbound containers actually loaded has increased by only 18% whereas the number available to be loaded increased by 25%. The number of containers handled by loading machines did increase by 25%, as those not put onto trains were unloaded from tracks and put into temporary storage. Machine utilization did not increase by 25% but only by 17% because the average distance the lift machines had to travel per container handled decreased by 10%. The increased workload meant that tasks tended to be closer together.

Run # 2 had the same traffic level as Run # 1, but had one additional lifting machine operation during all three shifts. The extra capacity has improved customer service, and allowed more containers to be loaded onto outbound trains. Performance was not as good as the base case, as customer delay was still 23% worse, and the increase in outbound loadings was not yet up to the desired 25% increase.

For the third run, one more lifting machine was added, but just for the peak shift from 08:00 to 16:00 hours. Now customer service has improved; delays being 31% lower than the base case. All outbound containers were able to be loaded. Machine utilization was lower than the base case as more capacity was added than was necessary to complete all the work available.

This simplified example shows how the model can be used to study a real terminal. Other application studies would include other resources in addition to lifting machine capacity, such as storage capacity, trackage and gate activities.

The model is currently being used in three specific areas. First, the model has been used during the redesign of CN's Montreal island container terminal. Secondly, the model is being used in the development of a five year machine requirement plan for CN intermodal. Third, the model is being used to assess the effect that changes in traffic volumes will have on CN's two major container terminal yards.

## 4. CONCLUSIONS

The Container Terminal Model (CTM) comprises a computer simulation model and post-simulation graphical output package. Together they form a very powerful system for analyzing the effect of alternative equipment, layout and operating procedures at an inland container terminal. The postprocessor adds an extra dimension to standard simulation output by dynamically showing the movements within a terminal.

Testing and validation of the CTM was carried out using data from CN's Conport terminal in Toronto. Current traffic levels, projected traffic increases and the effects of additional machines in alleviating yard congestion were examined. The CTM is being used on an on-going basis in CN's studies of container terminals.

The graphical postprocessor is a prototype developed as a compromise between traditional simulation methods and fully interactive graphical simulation. The postprocessor serves two purposes.

First, it is very effective as a means of presenting results by showing the simulation behavior. Management and operations personnel can easily understand the steps the simulation goes through to generate results, increasing their confidence in the model.

Secondly, the postprocessor is a valuable tool in debugging the model. It is particularly useful in studying event sequencing, which must be done in program verification and validation.

## DISCUSSION ON
## PRESENTATION BY I.R. GRUNWELL & P. ROSSI

DON WOODEN (Consultant): Your animation showed only one activity at a time. Does the model, or simulator, simulate in the sense that you can run several lifters or cranes simultaneously? It has to or you would never get through a day without operating all the equipment simultaneously.

I.R. GRUNWELL: It operates all the equipment simultaneously, - say five loaders, two gantry cranes, four tractors etc. The operation was simplified for the purpose of video to show the functions. Every function that is done in a simulation is shown on the video.

DON WOODEN: A real simulation of this would be a real busy picture.

I.R. GRUNWELL: It would. If you look at Conport, there are 13 different storage areas that are defined, and about six lifters, - so it is very busy.

I.R. GRUNWELL: (In reply to unidentified speakers) Monport is in Montreal. Conport is in Toronto, in North Toronto, next to MacMillan yard.

R.L. SPACK (Transportation Consultant): Have you tried this on the operation of the yard, to change the operation of the yard?

I.R. GRUNWELL: No we haven't.

D.H. WALKINGTON (Chairman): How did the actual at Montreal compare with your simulation? Did it verify all right?

I.R. GRUNWELL: Yes, within one or two percent, in terms of service time, machine utilization, travel time per machine, distance travelled, etc. Do you want to say something, Paul?

P. ROSSI (CN): To validate the model, engineers went to Conport, the biggest yard, and measured operations for a couple of weeks. Then they ran a simulation and compared them. The results were generally within 2%.

D.H. WALKINGTON: Do you feel that it actually did prove its worth in the design of that facility?

I.R. GRUNWELL: Yes.

D.H. WALKINGTON: It obviously has taken a lot of work to develop that simulation.

I.R. GRUNWELL: Yes. From our experience we would say that compared to classification yards, intermodal yards are a lot harder to simulate.

K.C. TIKKANEN (Canadian Transport Commission): What sort of a dispatch system do you have - (inaudible). Is it a radio based system?

I.R. GRUNWELL: In terms of the yard itself? Or do you mean in terms of how the simulation works?

K.C. TIKKANEN: What governs the movement of the men and machines?

I.R. GRUNWELL: One of the more complex parts of the simulation is determining what is the next task. If there is a train to be unloaded, it will usually be started first; but there may be a call to serve a customer which may have a higher priority. There could be free competition from other loaders. For example, should a loader travel 200 yards to serve somebody and then have to come right back again when another loader is finishing up close by. I should let Paul Rossi reply since he put in the priority logic. He can describe it better than I. There is a complex set of rules built in similar to what happens in real life. You might say there should be a real dispatching system in the yard and we may see that sometime in the future.

UNIDENTIFIED DELEGATE: What determines the demand on this system? I understand how you decide what to do next; do you load in the demand for every individual movement?

I.R. GRUNWELL: The simulation starts after a shift change when all of the machines are ready to load or unload trains, and service customers. As soon as customers get to the gate, they queue up; gate service is measured too. We can look at different ways of processing through the gates, using more servers or less servers.

SAME UNIDENTIFIED DELEGATE: Do you load in a list of customers and the time they arrive with their inbound load, and likewise when they come in with an empty or an outbound load?

I.R. GRUNWELL: That's right. You build it into the probability distribution, which defines the customer arrival and the train arrival at the yard.

# BC RAIL'S ADVANCED TRAIN CONTROL SYSTEM

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## ABSTRACT

The paper commences with a brief outline of BC Rail's endeavours, during the early 1970's and the period from 1979 to 1984, to implement the Location, Identification and Control (LIC) System. The joint Railway Association of Canada (RAC) and Association of American Railroads (AAR) Automatic Train Control Systems (ATCS) is described followed by a description of BC Rail's recent efforts to implement an ATCS on their North Vancouver-Squamish subdivision, utilizing the components of LIC which are ATCS compatible.

An overview of the ATCS system adopted by BC Rail is provided. All major components of the system are identified and their functions described. The components described include:

- host computer
- dispatcher man-machine interface
- network manager
- cluster controller
- radio site equipment
- engine equipment
- caboose equipment
- wayside equipment
- MOW equipment

Detailed descriptions are given of:

- the data communications protocol explaining how the problems encountered in the past have been overcome
- the engine equipment, particularly the manner in which the main processor interfaces with the processors associated with the various peripheral devices
- the graphics used with the cab display unit.

# BC RAIL'S ADVANCED TRAIN CONTROL SYSTEM

## 1.0 INTRODUCTION

This paper presents an overview of the Advanced Train Control System presently under development at BC Rail Ltd., under the joint sponsorship of Transport Canada and BC Rail Ltd. NKG Systems Ltd. is responsible for communications and field hardware and software; BC Rail Ltd. is responsible for host hardware and software and for the operational aspects. The system is in operation on a trial basis between North Vancouver and Squamish, British Columbia.

BC Rail became interested in train automation in the early 1970's. In 1974, BC Rail implemented a one-way system employing transponders to report train location over the microwave system. In 1976, the system was enhanced to permit delivery of text messages to a cab display in the locomotives.

From 1979 to 1984, BC Rail attempted to implement a more sophisticated system of computer-assisted train control entitled LIC, the acronym of location, identification, and control. In brief, the LIC system consisted of the following major components:

- o duplicated host computer
- o dispatcher man-machine interface
    - CRTs with graphic track status display
    - CRT terminals with function and alphanumeric keyboard
    - hard copy printers
- o duplicated data communications (front end) processor & modem
- o microwave channels
- o UHF base stations located along the route
- o locomotive equipment
    - UHF mobile radio & modem
    - engine logic unit
    - axle generator optically coupled to an odometer
    - cab display unit
    - transponder interrogator
- o caboose equipment
    - UHF mobile radio & modem
    - transponder interrogator
- o track-located transponders

Data communications was undertaken directly between the data communications processors and the train units. A polling protocol using BCH coding was utilized.

Extensive testing of the system was undertaken to determine whether the system was acceptable for operational service. The tests found deficiencies in numerous areas of the LIC system. The conclusion drawn by BC Rail was that the LIC system could not be put into operational service. One major problem area was the UHF data communications sub-system; in very simplistic terms, the system was not able to cope with Rayleigh fading, i.e. multipath, with the consequence of an unacceptably low level of successful communication.

## 2.0 THE RAC/AAR ATCS PROJECT

Prompted by increased competition from the trucking industry, North American railways today recognize that they must find ways to reduce operating costs, increase safety, and maximize use of existing facilities. The railway industry believes that the implementation of microprocessor-based technology could result in productivity increases of notable magnitude. Accordingly, the Railway Association of Canada (RAC) and the American Association of Railroads (AAR) have sponsored a massive program to bring current technology into railway operations. The program is entitled Advanced Train Control Systems (ATCS).

RAC/AAR wishes to achieve much more than encouraging the use of current technology; RAC/AAR wishes to foster standardization in ATCS, as the air transport industry has achieved with advanced technology. To this end, RAC/AAR prepared the ATCS operating requirements. The document identifies the sub-systems, the functions, and the modules which will comprise standard ATC systems.

After finalizing the operating requirements, RAC/AAR engaged ARINC Research Corporation, in association with Transportation and Distribution Associates, Inc. and Lapp-Hancock Associates Limited, to undertake conceptual and detailed system engineering to define performance specifications, technology constraints, and critical interfaces for the modules to be used in the various ATCS sub-systems. In August 1985, ARINC submitted its first report, which identifies the functional components for ATCS. Detailed equipment performance specifications are expected to be completed by the end of 1986. The development and testing of ATCS products by suppliers is expected to take place in 1987. It is foreseen that, commencing in 1988, individual railways will begin implementation of ATC systems, with complexity appropriate to their requirements and resources.

## 3.0 RE-DESIGN CONSIDERATIONS

Although BC Rail was not able to put the LIC system into operational service, BC Rail was not discouraged. It was noted that many of the LIC components functioned quite satisfactorily, and BC Rail decided to continue development of the train control system. About the same time, RAC/AAR had officially launched the ATCS project, and in fact BC Rail was, and remains, active in the RAC/AAR ATCS Project. BC Rail thus decided that further train control developments at BC Rail must be ATCS-compatible. At this stage, however, only the ATCS operating requirements had been established by RAC/AAR, and ARINC was just "coming on-board". BCR decided to proceed carefully with their system re-design, keeping regular contact with ARINC to monitor the direction of their thinking, reusing satisfactory LIC components where feasible, and designing all aspects of the new train control system to be as modular and flexible as possible. Within this framework, BC Rail's advanced train control system was conceived. BC Rail views this current development phase largely as a research activity in parallel with the ATCS project, with the prime purpose of implementing a functionally acceptable data communications system between the dispatch centre and the trains, and providing a "test-bed" on which various ATCS concepts and products can be put on trial.

In the re-design, some significant changes in system concept were made, notably:

- o distributed system architecture, i.e. microprocessor-based devices relaying information
- o X.25 polled communications between dispatch centre and base stations
- o X.25-like contention communications between base stations and mobile units using a modified EEA protocol for full duplex data communications over UHF mobile radio
- o cabooses communicating with the locomotive, instead of the radio site
- o more powerful host hardware & software
- o ability to handle non-equipped trains as well as trains in yards

## 4.0 SYSTEM CONCEPT

The major components in BC Rail's advanced train control system concept include:

- o host computer
- o dispatcher man-machine interface
- o network manager
- o cluster controllers
- o microwave channels
- o site control units
- o locomotive processing units and peripheral devices, i.e. graphic display unit, end-of-train unit, odometer, etc.
- o wayside processing units (including track sensors)
- o maintenance-of-way processing units, i.e. portable terminals

A block diagram of the system configuration is given in Figure 1. As shown, the system consists of five sub-systems, namely:

- o central sub-system
- o communications sub-system
- o train sub-system
- o wayside sub-system
- o maintenance-of-way subsystem

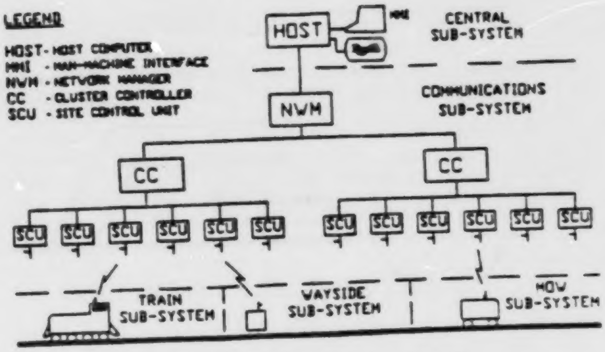

FIGURE 1 - SYSTEM BLOCK DIAGRAM

### 4.1 Central Sub-System

The central sub-system comprises the following components:

- o multiple processor host computer
- o dispatcher man-machine interface
  - CRT terminals with function and alphanumeric keyboard
  - CRTs with graphic track status display
  - CRTs for display of information relating to non-equipped trains
  - hard copy printers

Host software modules include:

- o host network manager
- o command manager
- o network communications interface
- o dispatch communications interface
- o debugger/simulator
- o voice issued train orders

The man-machine interface is driven by the host computer, and remains largely unchanged from that of the LIC system, except that special displays for non-equipped trains have been added. An illustration of the graphic track status display is given in Figure 2.

The host, in response to dispatcher or software-generated commands, instructs the network manager to deliver a message to a specific destination, e.g. a new authority to a locomotive.

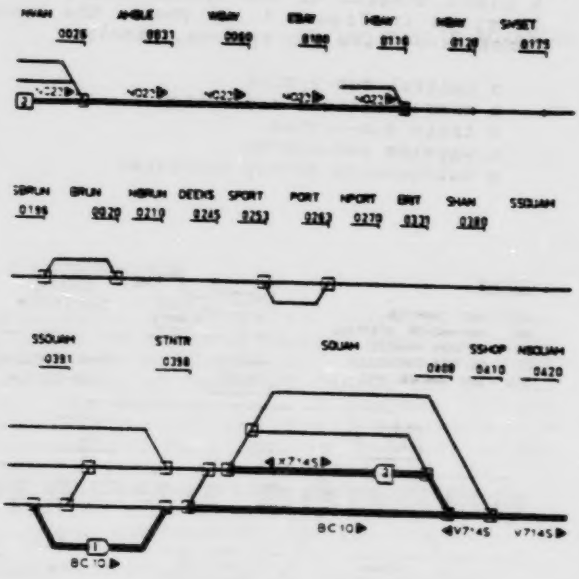

FIGURE 2
GRAPHIC TRACK STATUS DISPLAY

### 4.2 Communications Sub-System

The communications sub-system comprises the following components (all of which are duplicated):

- o network manager
- o cluster controllers
- o site control units
- o microwave channels

The network manager maintains in its data base the location of all active mobile units, i.e. the serving cluster controller and site control unit. The network manager relays the message to the appropriate cluster controller. The network manager is linked to each cluster controller by microwave channels and 9600 bps modems.

Cluster controllers are located at selected locations along the microwave system. Each cluster controller is connected via microwave channels and 9600 bps modems to up to six site control units. The cluster controller receives the message from the network manager and relays the message on to the required site control unit. The cluster controller also maintains the current position of each active mobile unit, so that the message is forwarded to the appropriate site control unit.

The site control unit consists of three processors, namely:

- o message processor for communication with the cluster controller
- o message processor for communication with the UHF radio system
- o site processor

The first message processor receives th message from the cluster controller and, i acceptable, passes it to the site processor the radio cell manager. The site processo stores and queues messages for the individua mobile units. The site processor als examines its file of mobile unit position and its radio coverage profile, an determines whether conditions fo transmission to the destination ar sufficient. The site processor relays eac message to the second message processo which, in conjunction with the minimum shif keying (MSK) modem, transmits the messag over the UHF radio system at 1200 bps t the destination, ie. the train, wayside, o maintenance-of-way sub-systems.

### 4.3 Train Sub-System

The train sub-system comprises the following units located on the locomotive:

- o UHF mobile radio and modem
- o message processor
- o locomotive processor
- o graphic display unit
- o alarm annunciator
- o hard-copy printer
- o function & alphanumeric keyboard
- o axle generator optically coupled to an odometer
- o transponder interrogator
- o end-of-train unit (train integrity detector)
- o locomotive health sensors

The UHF mobile radio and modem demodulate the transmission and pass the message to the message processor. The message processor checks the destination and integrity of the message and, if acceptable, acknowledges receipt and passes the message to the locomotive processor. If the integrity of the message is not acceptable, the message processor advises the site control unit accordingly and the message is re-transmitted.

The locomotive processor checks the message for syntax and conflicts and, if not acceptable, informs the host computer. If the message is acceptable, the locomotive processor stores the message, alerts the operator with the alarm annunciator, and displays the incoming message on the graphic display unit. In the case of authority messages, the operator must acknowledge the message, and the acknowledgement is relayed back to the dispatcher. If the operator does not acknowledge the message within a specified time, an alarm message is relayed back to the dispatcher. If the operator wishes, he may obtain a hard copy print-out of any message stored in the locomotive processor. The locomotive processor has 64 Kbytes of RAM allocated for message storage.

Via the transponder interrogator, the locomotive processor obtains absolute position information. When the interrogator in the locomotive passes over a transponder, the 200 KHz output of the interrogator activates the transponder. The transponder, using the 200 KHz energy which has been received through inductive coupling, transmits a modulated 27 MHz signal carrying its unique identification. From the unique identification received, the locomotive processor determines the position of the locomotive.

The locomotive processor obtains the instantaneous speed of the locomotive from an odometer, which is optically coupled to an axle generator. The locomotive processor calculates current position and acceleration of the train. Position is corrected each time the locomotive passes over a transponder.

Various locomotive health sensors can be connected to the locomotive processor.

The end-of-train unit monitors train continuity by checking the brake line air pressure, and advises the locomotive processor in the event of a sudden drop in air pressure. More sophisticated end-of-train units are able to also measure coupler tension and compression, as well as acceleration.

The caboose is equipped with a subset of the locomotive equipment, namely:

- o UHF radio and modem to communicate with the locomotive
- o message processor
- o transponder interrogator

The caboose equipment advises the locomotive when it has passed over a transponder.

The ATCS specifications will also provide for caboose-less trains. The BC Rail system is able to accommodate this case as well. In such case, the locomotive processor, knowing that the train integrity is being maintained from the end-of-train unit, can calculate when the last car has cleared a block; alternately or additionally, positive clearing to the rear can be confirmed by wayside detectors.

An electroluminescent graphic display unit provides the following to the operator:

- o graphic track profile (grade & turn)
- o current speed, required speed, and next speed
- o current authorities
- o block activity (current block, four blocks forward, & one block rear)
- o yard activity
- o stored text messages

An illustration of the graphic display unit is given in Figure 3.

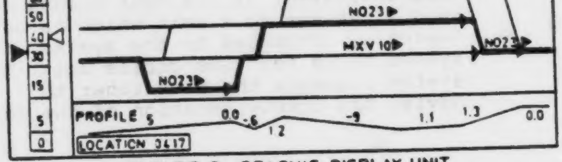

FIGURE 3 - GRAPHIC DISPLAY UNIT

### 4.4 Wayside Sub-System

The wayside sub-system concept has not yet been fully developed, but is foreseen to consist of:

- o UHF radio and modem
- o message processor
- o wayside processor (similar to the locomotive processor)
- o track devices, i.e. switches, hot box detectors, slide detectors, etc.
- o transponders

The wayside sub-system would contend for and communicate with the site control units in the same manner as the train sub-system. The network manager, cluster controllers, and site control units would handle communications as with the train sub-system, except that wayside unit locations would remain fixed. Via the wayside sub-system, the dispatch centre would be able to collect track status information, e.g. switch position.

### 4.5 Maintenance-of-Way Sub-System

The maintenance-of-way sub-system concept also has not yet been fully developed. As foreseen, it would consist of:

- o UHF mobile radio and modem
- o message processor
- o portable terminal

The maintenance-of-way sub-system would contend for and communicate with the site control units in the same manner as the train sub-system. The network manager, cluster controllers, and site control units would handle communications as with the train sub-system, except that mobile unit locations would be manually input.

Via portable terminals, maintenance-of-way personnel would be able to exchange information with other portable terminals, as well as with the locomotives, wayside equipment, host computer, and dispatcher.

## 5.0 DATA COMMUNICATIONS

### 5.1 Message Distribution Philosophy

The data communications network uses a distributed architecture, with intelligent devices relaying messages from one to another. Upon receipt of a message, a device checks the message and, if acceptable, signifies its acknowledgement by returning the message to the sender with the message control bits changed. If the message is not acknowledged, the sender records the error and re-transmits the message.

In addition to hardware acknowledgement by each device, the user must also acknowledge the message in the case of authority messages. When the engineman acknowledges receipt of an authority message from the dispatcher, the complete message, with only the message control bits changed, is relayed back to the dispatcher.

Messages may be sent to single destinations or broadcast to all units. In the case of broadcast messages, messages are relayed to the appropriate site control units and are broadcast to the units in each cell. All units must acknowledge the broadcast message. Depending on the number of units that fail to acknowledge, the message is either re-broadcast or re-transmitted as a series of single destination messages.

### 5.2 Data Communications Protocols

The X.25 protocol (level 3) is used to transmit messages between source and destination. Each communications path between the network manager and each active UHF mobile and stationary unit is given a unique identity. The network manager, cluster controllers, and site control units maintain files with the current cell locations of all active mobile units. When the network manager wishes to send a message to a mobile or stationary unit, the unique identifier of the required logical path is put in the packet header.

For data link control, two different protocols are used, namely:

- o for communication over microwave channels, the ISO high-level data link control (HDLC) protocol in a polling mode
- o for communication over UHF channels, the European Engineering Association (EEA) preferred data transmission system for land mobile radio using binary format, modified for contention control with bid/grant access and for error correction

An illustration of the modified EEA protocol frame structures is given in Figure 4.

### 5.3 UHF Network Contention

The site control unit functions as the radio cell manager. Cells may contain up to 20 mobile and stationary units. This maximum number has been established on the basis of response time requirements, rather than hardware or software limitations.

When a mobile or stationary unit wishes to communicate with the site control unit, it first determines whether the channel to that site control unit is free and, if so, sends the required bid signal. The site control unit, if it does not wish to transmit its own message, then returns the grant signal, and communication then takes place. The site control unit then transmits periodic grant signals to indicate to the other units that the channel is in use.

Should two units send bid signals that collide, the grant signal will not be returned, and the units assume that a collision has occurred. Each unit waits a minimum plus a random time interval before attempting to re-bid.

ACCESS BID

| PREAMBLE (16 BITS) | BID CODE (16 BITS) |
|---|---|

ACCESS GRANT

| PREAMBLE (16 BITS) | GRANT CODE (16 BITS) |
|---|---|

MINIMUM MESSAGE

| PREAMBLE (16 BITS) | DATA SYNC (16 BITS) | ADDRESS CODE WORD ( 64 BITS ) |
|---|---|---|

ADDRESS CODE WORD CONSISTS OF

| | |
|---|---|
| - CONTROL | 3 BITS |
| - PROCESS | 5 BITS |
| - SOURCE ADDRESS | 12 BITS |
| - DESTINATION ADDRESS | 12 BITS |
| - MESSAGE LENGTH | 4 BITS |
| - PROCESS ARGUMENT | 12 BITS |
| - CRC | 16 BITS |

OPTIONAL DATA CODE WORDS (UP TO 15)
FOLLOWING ADDRESS CODE WORD

| DATA CODE WORD ( 64 BITS ) |
|---|

DATA CODE WORD CONSISTS OF

| | |
|---|---|
| - SIX BYTES | 48 BITS |
| - CRC | 12 BITS |

FIGURE 4
MODIFIED EEA PROTOCOL

The bid and grant frames do not identify the bidding unit. The bid and grant frames consist of 16 bit patterns which are unique to the cell. This is done to reduce the time required for the bid/grant process. To reduce the possibility of a unit detecting a grant signal intended for another unit, the bidding unit must detect its grant signal within a narrow time slot.

### 5.4 Error Detection & Correction

Two levels of message security are utilized. Firstly, all message packets contain 16 bits for cyclical redundancy check (CRC). If no errors are detected by CRC, the message is accepted. However, if errors are detected, the message is re-transmitted. If the re-transmitted message also contains errors, a "bit voting" algorithm compares the two message fragments and attempts to correct the message. This technique facilitates correction of up to six bytes of data in error.

### 5.5 Mobile Seek & Mobile Logon

Mobile units that are not logically connected to the system, i.e. idle units or units entering ATCS territory, become connected via one of the following procedures:

- o Host-Initiated: If the host wishes to send a message to a unit which is not logically connected to the system, the system hunts for the mobile unit. The system requests the dispatcher to advise the likely location of the unit.

- Unit-Initiated: When a train enters ATCS territory, the engineman may initiate the "logon". In this case, the mobile unit seeks the network by monitoring the signal strength and signal quality from site control units in the area, and attempts to communicate with a site control unit.

## 5.6 UHF Radio System

All UHF radios are full duplex radios operating with open squelch. Locomotive (as well as the future wayside and maintenance-of-way) radios operate as half duplex. Adjacent cells may be on the same frequency, but different frequencies are preferred for traffic reasons.

The minimum shift keying (MSK) modems, also known as fast frequency shift (FFSK) modems, use one cycle of 1200 Hz and one-and-a-half cycles of 1800 Hz to signify binary "1" and "0" respectively. Each binary "1" and "0" subcarrier waveform starts with either 0 or 180 degrees. The modem detects the "zero crossover" of the waveform. The MSK modems were selected because of their ability to cope with large burst errors.

## 6.0 BC RAIL'S TRIAL SYSTEM

For reasons of expediency and to minimize expenditure at this point in time, BC Rail has thus far only implemented portions of the above described system concept. The prime purpose of the trial system is to evaluate the data communications aspects of the system. The trial system comprises the following non-duplicated components:

- central sub-system as described above
- network manager
- one cluster controller, integrated with the network manager
- four site control units
- microwave channels
- two equipped track vehicles (a work locomotive and a rail diesel car)
- one equipped road vehicle
- more than 40 existing transponders

The acceptance test is scheduled to commence in June 1986.

## DISCUSSION ON PRESENTATION BY B.E. MRAZEK

R.C. KULL (Signalcom Canada): The total system configuration implies safety-related data needs to be transmitted from the locomotive back to the dispatching centre. Are you satisfied that the 16 bit CRC and that added with error correction that you implied, is adequate protection?

B.E. MRAZEK: Dan (Gudmundson), do you want to take that one?

D. GUDMUNDSON (B.C. Rail): We only have 48 bits of data inside our 64 bits code word with 16 bits of CRC which allows us to detect 8 bits in error in our 48, so if we run that polynomial out we can work out our probability of undetected error, which gives us approximately 10 to the minus 12. If we take our forward error correction algorithim, our bit voting, and put that into our calculation, we would come up with a figure about 10 to the minus 9. You have better chance of being hit by lightning.

R.C. KULL: Is that 10 to the minus 9 probability of accepting bad data?

D. GUDMUNDSON: Yes, but that is only at link level. The next thing that happens is that the message is passed through to the conflict processor, which will check the integrity of the authority that has been issued. If it detects an error, then it generates a conflict with issued authority message and sends it back to the host.

R.C. KULL: When do you envision the hardware to be implemented? What timeframe?

D. GUDMUNDSON: It is being implemented right now.

R.C. KULL: Is it in service?

D. GUDMUNDSON: It is not in service. Our purpose is to be able to develop the technology, prove that the technology is valid, that the operational parts are adequate, that it is safe, and then take it from there.

R.C. KULL: Then there is no definite long range plan for service implementation?

D. GUDMUNDSON: Not at this time.

R.C. KULL: Okay, thank you.

R.J. POMEROY (DSL): Can I ask you what CRC code you use?

D. GUDMUNDSON: It is specified in the protocol. It is 15 bits CRC with parity interlaced in the CRC. It is not CCITT nor is it CRC16.

M. AVNI (TDC): You did not mention whether your communications system is using single frequency or multifrequency. If it is a multifrequency, do you have scanning receivers or, how is the communications arranged?

B.E. MRAZEK: You are referring to the UHF sub-system?

M. AVNI: Yes, the UHF sub-system.

B.E. MRAZAK: Ideally, each site control unit operates within its own set of frequencies. We have changing frequencies per cell. It does not have to be, but for traffic reasons, we would prefer to do that. I mentioned that the bit code and the grand codes were unique codes so that you could have two cells operating on the same frequency but, because the codes are different, they would not conflict. For traffic reasons, we prefer to keep them on different frequencies.

M. AVNI: If you use different frequencies in different areas, how do you handle the train receivers? Are they scanning receivers that can automatically switch from one to another as they go from one zone to the next?

D. GUDMUNDSON: We store the RF profile for each given cell. As the train moves along, it is judging the RF profile and determining the following: what frequency should it be on, what bit code should it be using, should it send this message in degraded mode (i.e. twice repeated) to allow for correction, or should it send it in normal mode (i.e. once only)? Chances are better than 80% of succeeding on the first attempt.

M. AVNI: This is the explanation for the case of a call initiated by the train. What happens in the case where you have an initiation of a call from the centre such as the 'seek' operations that you discussed? I guess there has to be knowledge of which frequency zone you are in or to allow for scanning so that without knowing, you can see the scan fast enough without losing this kind of a call.

D. GUDMUNDSON: If the train is logged in, yes it does seek, it does scan all the channels.

M. AVNI: You are using scanning receivers?

D. GUDMUNDSON: Yes, but it is not a scanning radio. The software itself drives the scanner. There is a slight difference.

M. AVNI: Thank you.

I.R. GRUNWELL (CN): You showed the cab graphic display. I am wondering, since you have the profile in there, how often is that getting updated as the train is moving? Have you done any evaluation of how much information you are sending to the cab or is that all local, based on a position?

D. GUDMUNDSON: Profiles are all stored locally inside the locomotive. The only time they are ever changed is if there has been a physical change made to the track.

I.R. GRUNWELL: If I was sitting in the cab, how frequently would I see the display changing because obviously if I move 100 feet, then you might want to drive the profile along. How are you planning to do that?

D. GUDMUNDSON: The profile moves every 10th of a mile. The authority display portion moves as the train clears blocks of authority. There is the ability to page throughout the subdivision or backwards down the subdivision. The train sub-system has the capability of storing all of the other authorities for the other trains on the subdivision. That is done through a multicast broadcast system through site controllers.

# ADVANCED TRAIN CONTROL SYSTEMS

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## ABSTRACT

This paper describes the progress made to date with the Advanced Train Control Systems project.

Overall objectives with respect to train operations have been established; viz. safety, economy and reliability. Operating requirements, defined by a working group representing five Canadian and two U.S. railroads, have been published. That working group, augmented by representatives of two additional major U.S. railroads now serves as the project steering committee. Other railroads and the supply industry have been kept abreast of progress through two large public meetings. Development of the systems engineering is being advanced.

# ADVANCED TRAIN CONTROL SYSTEMS

Early in this decade, the Railway Advisory Committee (now RAB) began fostering the idea that existing technology, particularly in the fields of micro-processing and communications, presented the means for significant improvement in the area of train control. A small group of Canadian and U.S. roads picked up on that idea and ATCS was born. Their approach was based on innovation, not invention. They were convinced that virtually all of the needed technology had been proved elsewhere - in the military, in space, in other industries and even in other railway applications

Objectives of the infant project fell into three main categories:

SAFETY
- ATCS must not compromise safety, in any respect, compared to existing systems.
- ATCS must enhance safety wherever possible, through enforcement of authority limits and speed limits, and warning of dangerous conditions.

ECONOMY
- ATCS should be less costly to install, and to modify later, than is the case with conventional systems.
- ATCS, expected to be less hardware intensive in the field, should be cheaper to maintain.
- ATCS should improve the productivity of plant, fuel and manpower.

OPERATIONS
- ATCS should improve reliability of customer service in a highly competitive transportation market.
- ATCS should enable better utilization of plant capacity.
- ATCS should be significantly less disruptive to normal rail traffic during installation or upgrading, compared to conventional systems, such as CTC.

Seven roads assigned representatives to a working group that set out to define the operating requirements for a new, modular, array of systems for train control, with the foregoing objectives. They were:

- Algoma Central Railway
- British Columbia Railway
- Burlington Northern Railroad
- C.N. Rail
- C.P. Rail
- Norfolk Southern
- Seaboard System Railroad

Advanced Train Control Systems "Operating Requirements" was published in April of 1984 and the project was granted immediate joint sponsorship by The Railway Association of Canada and the Association of American

Railroads. The working group that wrote the requirements was asked to continue as a Steering Committee, to carry on with the project's development, and Mr.P.J.Detmold was named General Manager.

Preparation of Operating Requirements concluded Part 1 of the project and a public meeting was held in Toronto in June 1984, to:

- Identify for the Supply industry the large market represented by RAC and AAR sponsorship.
- Discuss the requirements of that market.
- Invite Supplier participation in the project.
- Describe Part 2 - independent system engineering.
- Request proposals from Organizations with Systems Engineering expertise.

For support and monitoring of the systems engineering process, members were selected from people that are highly skilled and respected in their fields, to form railway industry Task Forces in these functional categories.

Systems Engineering
Economic Assessment
Communications Engineering
Computer Systems
Locomotives
Operations
Public Affairs
Regulatory Liaison
Research
Signal Engineering
Track & Roadway Engineering

The initial Systems Engineering work was to identify and evaluate appropriate technologies, consider how they could best be adapted to our purposes and determine how they might be integrated into a practical system architecture.

After a meticulous selection process, a contract was signed in January 1985 with a consortium of:

- ARINC Research Corporation, systems engineering specialists from Annapolis MD.
- Transportation & Distribution Associates Inc., railway specialists from Philadelphia PA.
- Lapp-Hancock Associates Limited, communications specialists from Ottawa Ontario.

They provided us with: a listing of functional components designed to meet the Operating Requirements (August 1985): a detailed technology evaluation (October 1985): and a proposed system architecture (December 1985).

Representatives of Southern Pacific Transportation Company and Union Pacific Railroad joined the Steering Committee, and a senior representative of the AAR Research & Test Department also became a member. At a plenary session of Steering Committee and Task Forces in the Fall of 1985, approximately 80 railroaders participated, coming from 18 different roads that included most of the major North American carriers.

A second public meeting was convened in Atlanta on February 5, 1986, to update all concerned on progress through Part 2, inform the meeting of future plans for the project, and provide opportunity for discussion and inquiries.

Part 3 - Drafting Component Specifications - will involve committees of railway and supply company representatives that are skilled in writing detailed specifications in those fields particularly related to each functional component. Suppliers were given a list of components at the Atlanta meeting. Forms were distributed, on which companies were invited to indicate what committees they wished to join, in order to participate in the preparation of specifications for components they expect to develop. The process will commence with production of preliminary drafts by engineers of the ARINC consortium. Subject to agreement by the appropriate Task Forces, these will be circulated to the Component Specification Drafting Committees (CSDC) for recommendation of modifications as they may see fit.

The underlying principle of component specification will be the "Form-Fit-Function" (FFF) concept. The ATCS Specifications will document stated requirements of railroad operating and technical professionals concerning ATCS hardware and software - with the intention of influencing the design of new equipment in such a way as to provide compatibility and standardization, without limiting the internal design approaches of individual manufacturers.

These benefits are perceived in applying FFF to the design of ATCS Specifications:

- It is a successful major industry application, being the procedure used by the airlines for acquisition of avionics equipnment;
- It places a premium on quality and cost, because superficial differentiation becomes less effective:
- It spurs investment in R&D, because that is the means toward either demonstrable improvement in quality or lower production costs that may be reflected in more competitive pricing.

An important attribute of FFF is supplier and technology transparency. It enables a user to combine modules from different suppliers in his system, and to replace a module with one from any supplier he chooses should new technology offer an improved or more economic component.

Part 4 - Research and Testing - was discussed at the Atlanta meeting as well. These activities will be initiated by ATCS, with the need for research being revealed by gaps that may appear in development of components by the supply industry. Testing of components, to confirm that they meet characteristics specifications, will probably be undertaken by independent laboratories, which will be selected by ATCS and authorized to certify qualifying components. Systems testing is expected to be a joint user/supplier activity, on a basis to be negotiated between them.

Software may become a principal railroad development activity. However, its modular nature and distributed processing (much of it on board the locomotive) may cause it to be less of an "Achilles Heel" than in more centralized systems of this magnitude. Vital functions are being identified by the Operations Task Force and Steering Committee of ATCS.

WHERE ARE WE TODAY?

- CSDC's are forming up and there have been organizational meetings of their chairmen.
- The first draft of ATCS Specification 100, OVERVIEW SYSTEM ARCHITECTURE, is in the hands of the Steering Committee and Task Forces, for their initial assessment.
- Other ATCS Specification drafts are in the production process.
- A plenary CSDC session is scheduled for October to integrate related specifications where necessary.
- The Steering Committee is moving on plans for component testing.
- Various Task Forces and committees are attending to global issues, such as frequency allocations and other government regulatory matters, and ensuring that any "reluctant dragons" in the railway industry are kept informed and encouraged about the project.
- Most major roads have internal committees, made up of senior people that represent the various technical areas, and who are considering potential applications, economics, test sites, etc., so that the advantages of ATCS may be exploited quickly, and that the predicted market will be there when the suppliers deliver the goods.
- Anticipating their adaption to meet ATCS Specifications, some standard products are already being offered for test. Several roads are actively considering these proposals, expecting that any experience gained will be mutually beneficial and perhaps expedite component development.

## DISCUSSION ON
## PRESENTATION BY E.W. BAYNTON

W. SERGEANT (CANAC): I have two questions. The first one is in relation to the instrumentation. All of the instrumentation is on a single screen. Much of this information is in the cab, - brake pressure gauges, the speedometer, etc. The only information that seems to need to be displayed in a different way is information coming from the transponders and the control information that is coming in from some central control point. Why does the duplicated information have to go on to the screen instead of using the instruments that are there?

My second question is in relation to reliability. We have a presentation of information on the screen. What do you see happening in case the screen goes blank because of a failure? Is there a second one somewhere or how do we look after that?

E.W. BAYNTON: In answer to your first question, the cab display is a demonstration to help people to sit back and run the thing. It is a simulation of ATCS used to gain some experience and to bring in to one place all the instrumentation. I am sure that I can speak for Union Pacific Railway (UP) when I say I don't think that they expect to have that as a screen on a locomotive. Certainly speedometers will be part of the locomotive. I think the final installation could follow the direction that the airlines seem to be going. Any one of those specific gauges or blocks of information can be independently shown on the screen. Final displays will depend on the experience that we gain from the things that BC Rail, UP, and other people are doing to find out what we really want to display on the screen. This is not intended to be a finished product and certainly it is not intended to clutter up the screen with redundant information.

There is no final decision on what happens if the screen fails. The ATCS Operations Task Force is looking at the value of a second screen in the locomotive for back-up. It might serve an additional purpose if it were more accessible to other crew members and not just to the engineman. A lot of work has to be done as the system evolves. It may depend on what sort of a back-up system we have. CMBS (Computer-assisted Manual Block System) is now being used to control trains on almost all CP Rail lines not equipped with automatic block signals. In this case, if we lose our data link, (similar to losing the display), we would go back to voice control until the system was up again. This would not prevent the control centre from utilizing its control logic that would prevent lapse of authority and that sort of thing. With ATCS superimposed on CTC (Centralized Train Control) with a high level of sophistication, then the CTC itself could be a fall-back control system.

Failures will happen, and the fall-back control system won't be as efficient as the primary system; but we expect to continue operating with less than many of the present systems do. We may very well have two units in the cab with one of them a back-up, but we will certainly have prescribed procedures for continuing to operate in the event that any part of the system fails, including the display itself.

D.H. WALKINGTON (Chairman): it is almost 5:00 o'clock, do you have a question that Earl can answer fairly briefly?

R.L. SPACK (Transportation Consultant): The Union Pacific demonstration may be a picture of what railroading might look like in 10 years. Is this level of sophistication expected to be used for a mainline operation, a branch line operation, or for operation everywhere?

E.W. BAYNTON: The very characteristic of ATCS is that it is not a system at all but a whole array of compatible components that can be put in to an infinite series of combinations to do things at any level of sophistication that a specific railroad requires. It can start as CMBS on a quiet branch line and be upgraded progressively to the most sophisticated system you might be able to dream up, without throwing away one level as you install another. One of the very important attributes of ATCS is its upward compatibility. It is not going to be always possible to identify the moment that ATCS is being launched. It is intended to grow a little at a time and, there it is. Today, when you move from train orders to CTC, you have to plan a long way ahead of the time that you are going to need it. When you start to install CTC is often when you need it most because the disruption is at a peak.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

## 3. PROCEEDINGS OF THE RAILWAY ADVISORY BOARD OPEN MEETING FRIDAY, JUNE 13, 1986

### 3.1 Opening Remarks by Chairman Mr. P.J. Detmold

Good morning ladies and gentlemen. This is going to be a meeting of the Railway Advisory Board, but a meeting of the Railway Advisory Board of an unusual kind in that most of the members are absent and a lot of non-members are present; but with that small exception, it will be a meeting of the Railway Advisory Board.

I would like to emphasize that this meeting has one purpose which overrides all others: it is to consider the usefulness of cooperative research. By cooperative research I think we should include both government assisted research which, with one notable exception (ATCS project) refers to most of what you have heard yesterday. It also includes commercial cooperative research arrangements of any other kind that either exist or you feel should exist. I would emphasize that what we want is your opinion! We have a firm purpose of reviewing this five-year Augmented Rail Freight Transportation Research and Development Program (ARFP). Has the program been worthwhile? Which project do you personnaly feel has been useful? Which ones do you feel otherwise about? Do you think we ought to carry out lots of small projects to make this a kind of mini-bank for assisting small researchers of one kind or another, seeding new activities each on a very small scale - or do you think we ought to go on a kind of "big bang theory" and have three or four huge projects? If we had many projects the size of the ATCS project there just would not be the talent to man them. We just would not get the people from the industry in Canada, or even in North America. I would ask you to think about these questions between now and coffee time after which we will talk about them.

We will begin by asking yesterday's chairmen of the four sessions to summarize their session. There will be time for discussion.

I welcome to this table my good friend Kelly Arrey, System Mechanical Engineer - Car, Canadian National. Kelly has been a tower of strength on these committees for a long time and I welcome him in place of Bob Radford who unfortunately had to be elsewhere today. I will ask Steve Cavanaugh if he would begin with the Motive Power session.

### 3.2 Summary of Technical Session #1 - Motive Power

S.D. CAVANAUGH (C.P. Rail): Thank you Mr. Chairman. The session on Motive Power yesterday covered a wide range of topics, beginning with Railway Electrification and Locomotive Fuel Saving devices. It moved on to Single Cylinder Diesel Engine development, Microprocessor Control for an AC Locomotive, Train Data Recording Systems and finally an Evaluation of Event Recorders. I am going to take this opportunity to review the abstracts of those papers for those of you who may not have been here yesterday and to refresh the memories of those of you who were.

## Railway Electrification

In his paper on Railway Electrification, Mr. Alfred Versailles of TDC expained how TDC's research and development on rail electrification had prepared Canada for possible future electrification of certain sectors of the country's rail system. TDC is supporting research in the following areas:

> Establishing the technical and economic characteristics of rail electrification.
>
> Developing guidelines for electrification including those needed for signalling and communications.
>
> Evaluating alternative electric and hybrid locomotive designs.
>
> Identifying the system requirements and the related costs of the specific electrification projects.

In that one topic alone, there are several areas for continued research.

## Locomotive Fuel Saving System

This second paper, on Locomotive Fuel Saving System, was given by Mr. Gaston Lévesque of DSL. This is a new concept to greatly reduce the wasting of fuel due to idling of locomotives and to the excess of power in a train consist. It has been fully implemented now on five SD40-2 locomotives. An automatic start/stop controller suitable for North American locomotives has been designed paying attention to safety, reliability, cost, ease of installation, operation and maintenance.

To achieve those objectives, full solid-state micro-processor techniques were used. Modern electro-mechanical devices were designed and specially structured software techniques were used. Practical railway locomotive experience was applied throughout the project.

Savings in the order of $20,000 per locomotive per year have been calculated from the results obtained during the testing of the prototype system. Five pre-production systems have been installed for larger scale testing.

## Facility For Medium Speed Diesel Engine Research and Development

The third presentation, by Mr. Malcolm Payne of Bombardier, gave us an overview of the Bombardier Single Cylinder Research Engine program (BSCRE). He described its evolution to a full capability research facility for medium speed diesel engines. These engines are suitable for locomotive, marine and generator sets.

This program, which started in 1982, has progressed to the final stages of phase III, which covered the calibration and qualification of the single cylinder 251 and 2400 BSCRE engine versions.

A description of the engines and test cells was given; also some of the R&D capabilities of the facility were highlighted, including the yet-to-be completed fuel and lube analysis lab and the turbo-charger development test rig.

### Microprocessor Control of AC-DC-DC-AC Locomotives

This paper was given by Mr. Michael Nixon of Synitek, Inc. With the inclusion of the MICAS computers on the program to retrofit BBC three phase AC traction on a CP Rail locomotive, a project was developed to optimize their use. The project involved the development of a systems laboratory facility and, in conjunction with the University of Toronto, a real time interactive simulation and test facility. The project then concentrated on the development of wheel slip control software as well as engine control, protection, optimization, and data logging concepts. In addition to the work, spin-off benefits came in the form of definitions for future hardware development.

### Train Data Recording Systems

This presentation was by Messrs Clark and Guevara of MPB Technologies, Inc. The purpose of the experimental Train Data Recording System (TDRS), developed for CP Rail and Transport Canada, was discussed along with software/hardware facilities which are now available. New features which are under study or are being developed were presented, along with a description of the modular TDRS approach proposed for day-to-day operational service.

### Evaluation of Event Recorders

Mr. Doug Dibble of TDC described an evaluation program of two commercially available event recorders: the Pulse model 48H8-C-10, and the Hasler-Teloc-2000 DR, undertaken by TDC at the request of the Railway Transport Committee (RTC), in conjunction with the RTC, Canadian National and CP Rail. The objective of the project was to determine the operational suitability of event recorders for accident investigation. The project included performance tests and analysis of reliability and maintenance data of locomotive event recorders that were potential candidates for installation on Canadian locomotives.

Both recorders would record at least the following eight required events: time, speed, throttle level, brake pipe pressure, independent brake cylinder pressure, locomotive initiated emergency, whistle and distance.

For the evaluation, 10 Pulse recorders were installed on CN locomotives, and 8 Hasler recorders were installed on CP Rail locomotives. During the evaluation period there were no operational or maintenance problems associated with the recorders. Accident simulation tests were performed that involved recording, in parallel, the identical signals that the event recorders were recording. For each test, the data from the different sources were compared and the event recorder data was generally found to be extremely accurate. The general test results for both recorder models indicated that the recorders could survive under the operating conditions encountered on a diesel locomotive and record and retain reliable data.

There are other projects related to Motive Power which are under way and listed in the hand-out that was given out by TDC yesterday at the beginning of the seminar. In all cases, these development efforts were made possible through funding from TDC.

I think we had a reasonable level of questions asked about each paper. There was certainly interest in all the papers given yesterday.

I guess that leaves us with what are the areas for future work. I think of the Railway Motive Power Development Study currently under way, and listed in your hand-out. Work is also being considered on the winterization of locomotives and other fuel-saving features through combinations of stand-by heating. These have been the ones that we have focused on more recently in the motive power group.

I will conclude and wait for questions or comments.

P.J. DETMOLD: Do we have any comments on what Steve has just said?

I have one, but I think I should give him a little notice of it. I would like to hear a little more about the 4744 AC locomotive. I will ask Steve to tell us something about that later in the morning. It seems to me to be quite significant that we should try this very different form of motive power on the continent whose power, though excellent, has become somewhat staid in its ways, if I may say so.

Do we have any other questions that you would like to ask Steve before we preceed? No? Well in that case I will call Michael Roney to the podium.

## 3.3 Summary of Technical Session #2 - Track and Infrastructure

M.D. Roney (CP Rail): Thank you Mr. Chairman. Session #2 on Track and Infrastructure illustrated how technology can be used to strengthen track structure. Presentations covered the strengthening of various track components. We talked about rail grinding and profiling to extend rail life, improved metallurgy to extend the life of railway frogs, the use of sub-ballast and geotextiles, and about use of geogrids to stabilize railway embankments. The researchers have all concentrated on an important first step, that is to describe in detail the cause and effect relationship between track loading and track component failure. Each has made a significant contribution to our understanding of the track materials with which we have to work. In so doing they have been able to suggest some methods of improving track structure to more economically support heavy axle loads and to address some of the heavier maintenance areas in track.

### Rail Wear and Contact Fatigue Model

Joe Kalousek of the Western Laboratories of National Research Council gave an excellent description of rail wear, illustrating how lubrication can effectively control guage face wear. At the same time, he showed that lubrication contaminates the rail top surfaces and reduces wear to the point that contact fatigue cracks initiate and propogate. He made the point that lubrication delays initiation of cracks but accelerates their propogation once these cracks reach the surface. These results have important implications in view of the trend to increase lubrication specifically to effect fuel savings. With good lubrication, Dr. Kalousek feels that surface cracks will branch into deeper layers of rail steel.

The solution is a technique that he terms "preventative grinding". This is quite a departure from current rail grinding practice which calls for the removal of corrugations in the rail surface when the cracks reach about 1/20,000 of an inch. Althrough such grinding may remove corrugations, many cracks are left behinds, particularly in the valleys of these corrugations, and will continue to grow until they result in early re-occurence of corrugations. I think those of us who look after grinding in our respective railroads will agree tht corrugations reappear in a shorter interval after first grinding and continue that way.

The preventative grinding technique that Dr. Kalousek proposes would call for frequent grinding to ensure removal of cracks before they appear or while they are still very small. According to his research, this could require only 1/2000 of an inch metal removal. Grinding would however be required approximately every 5 million gross tons on sharp curves and every 15 million gross tons on tangents. This contrasts with the current practice of grinding every 20 to 30 million gross tons. It would require a minimum of 30 stones and a single pass. The profile would concentrate on removing wheel contact with the gauge corner of the high rail and the field corner of the low rail, both of these being high stress contact. This particular feature is included in current profiles used by CN and CP Rail, although modifications would have to be made to accommodate this more frequent grinding which specifically tries to maintain more of the worn shape of the rail.

With the use of this preventive grinding technique, Dr. Kalousek expects a substantial increase in rail life, assuming, as well, full and effective use of lubrication to control the traditional modes of wear. Obviously railways will have to adapt to more frequent grindings. This implies increased train interference and railways will be looking to the suppliers for smaller, faster grinders to reduce grinding time. The interest in this proposal is very high.

## Improved Austenitic Manganese Steel For Railway Application

Dr. Bill Mackay spoke about the work on improving the alloy composition of austenitic manganese steel that he and Dr. Reg Smith have been conducting over a six year period at the Queen's University metallurgy department.

Cast austenitic manganese steel is currently used in frogs and cross-overs. It is a 100 year old type of steel and there has been an awful lot of skepticism as to whether this composition can be improved. It does work harden very well, is weldable and it can be cast fairly simply. Current frogs are certainly a weak point when we talk about the track that we want for the 90's.

The objective of this project was to improve the yield strength of this metal and improve its wear resistance while maintaining its good foundry characteristics, its weldability and response to explosive hardening. Those properties are, specifically, impact strength and capacity for work hardening. The approach that they have taken is to seek various alloy compositions which would develop hard globular carbides dispersed in the softer austenitic matrix of the steel, similar to what is done in forming tools. The Queen's University researchers talked about the need to control the dispersal of these carbides using alloy additions and/or heat treatments to assure that they do not network.

The research has shown some promising results. Initially the carbon content was dropped to improve weldability but this was found to hurt the yield strength. The current thinking of the researchers is that a slight increase in carbon within 1.2% would probably be good. Vanadium has been found to have a very positive influence on yield strength when used in small qualities. As a result the current thrust is to use vanadium as a principal alloy element. This has subsequently been combined with smaller qualities of molybdenum and certain minor multi-alloy compositions including such things as cooper has also been attempted.

There is still lots to do on this project. The permutations and combinations are great but they are proceeding with trying all sorts of different compositions, and certainly the trend seems positive. They have certain other findings of interest. One is that phosphorous may be very important in quality control on these castings, something which should come up in future specifications. De-carburization may require controlled atmospheric heating. At the same time they found that the existing CP Rail frog repair practice does not overheat the frogs. They found that some welding rods were better than others and the best was homemade in the labs at Queen's University. They have developed a wear impact simulator rig which they feel simulates very closely a wheel contacting the frog point and it will be used in all further evaluations of the alloying before they end up in a field trial.

They concluded that frogs must be treated as a premium product. Alloy additions alone cannot produce a long lasting frog. It is very important to have good processing practice, good quality control, good specifications, and good inspection.

## Full Scale Wheel/Rail Test Facility

Helen Tucker of the National Research Council reported on the design and building of a facility capable of testing a full scale standard gauge wheelset and associated brake rigging. This facility is being constructed by the National Research Council with partial funding from TDC. It is designed for extended wear tests of a month or more duration and the testing of wheelset components (brakes, wheels, bearings and axles) under controlled, yet realistic, environmental conditions. The facility will be unique because it is simulating at full scale, both rail/wheel and brake/wheel interface. The facility is small enough to allow control of temperature and the introduction of certain contaminates using environmental chambers.

The facility will use two driven rollers to simulate rails and will consist of a double frame wherein the flexure-mounted inner frame can move relative to the stiffer outer frame. This flexure mounting allows for positioning of the wheelset relative to rollers and for incorporation of load cells to measure the relevant force components at each roller. The wheelset will be positioned using ball screws and vertically loaded using hydraulic actuators.

This test facility is intended to simulate, as realistically as possible, actual wheel/rail contact conditions, without compromising mechanical simplicity or operating reliability. It is located in the Vehicle Dynamics Laboratory, NRC, Ottawa, with access to the recently commissioned NRC environmental chamber. It is to be available for use by the railway industry and for in-house research. It is just under construction at the moment but it certainly should be coming into operation very soon. Much of the discussion centered on the need to simulate lateral effects on the wheelset. Following the presentation, it was reported that this could be done on a limited scale through measures such as re-profiling the wheels and introducing differential wheel diameters.

## Track Structure Research - Presentation and Panel Discussion

### 1. An Overview of the CIGGT Track Research Program

The panel discussion was started off by S. Lamson, who is manager of the Track Research Program at CIGGT. Much of this program is under the sponsorship of TDC on a cooperative basis. The work centres on (1) track component improvement and (2) track system modelling. Achievements in the area of track component improvement include:

- A comprehensive manual on geotextiles selection and application.
- A detailed guideline on track design with or without goetextiles, for a range of existing sub-ballast materials.
- A better understanding of wood tie degradation that would lead to techniques for improving tie performance.
- An optimal rail profile which reduces existing rail corrugation and fatigue problems.

Mr. Lamson commented that the existing wood tie has been largely neglected over the years. We tend to make the step, the large step, to a concrete tie, without having really looked at incremental improvement of the wood tie. CIGGT is looking at wood tie improvement knowing that the industry can't afford to pay much for these improvements, given the service life we were getting.

He discussed the philosophy of rail profile design that CIGGT have developed for three operating railways, including Canadian Pacific. He talked about the work of previous researchers and particularly some of the Australian experience in developing a profile which reduces false flange contact by cutting away the field side of the low rail. This specifically attacks shelling on the high rail, cuts away the gauge corner and maintains some aspects of the Australian technique of assimetrically grinding rails to improve the rolling radius differential between the two wheels.

Achievements in the area of track system modelling include:

- A track system model consisting of 4 modules: vehicle dyanmics, rail life, tie life, surfacing and lining cycle.
- A data acquisition and analysis system, which permits the recording of track dynamic and permanent settlement as well as track geometry error growth.
- A set of vehicle/track dynamics interaction computer simulation models which permit a wide range of dynamic track force analyses.
- A comprehensive analysis of track maintenance using this model on an operating railroad.

Mr. Lamson demonstrated track costing based on a full description of the cause and effect relationship between the passage of a spectrum of loading over the track, the wear of track components and finally to their cost using actual data to categorize track roughness measurements from the CN Rail track geometry car and way-side measurements. Certainly this model will contribute much to our understanding of how cost can be directly affected by any system changes in the railway.

## 2. Reinforced Embankments

Mr. John Busbridge of Golder Associates defined reinforcing as consisting of geotextiles or geogrids which can be used to stabilize embankments in three groups of applications:

Fill slopes on good foundations.
Rehabilitation of natural slopes.
Reinforcement of fill to compensate for weak foundations.

He discussed a study that was done of actual embamkments. In order to precisely measure the performance of reinforced embankments and their foundations, three instrumented embankments were built up to failure at St. Alban, Quebec. One of the embankments was reinforced with two horizontal layers of what is called a Tensor SR-2 geogrid while a second was reinforced with a sand-filled geocell mattress, using the same quantity of reinforcement as used in the horizontal strips. To allow a direct comparison between unreinforced and reinforced embankments, the third embankment was unreinforced. All embankments were then built up to failure.

The calculations to failure indicated that the horizontal layers of reinforcement allowed over 30% increase in the failure height of the embankment. The geocell reinforcement was only about half as effective in increasing the critical height, so there was a definite effect demonstrated by using the strip reinforcement in the embankment. Data was presented which showed the performance of the reinforcement, the embankments and the foundation sub-soil. It was concluded that the main effect of the reinforcement was to maintain the integrity of the embankment as the foundation sub-soil deformed. No beneficial effect of stress distribution or reduction in deformation could be identified under the reinforced embankments. Strain in the geogrids was very small in failure. The horizontal layers of reinforcement were reported to be easier to construct than the geocell mattress and they were also reported to offer the greatest improvement in failure height for the same quantity of reinforcement.

With some definite results coming out on effectiveness, it remains for we in the railways to look at the economics. What can we trade off in terms of having increased embankment heights for the same side slopes versus what it is costing to reinforce with the geogrid type reinforcement?

## 3. Ballast and Geotextiles

Professor Gerry Raymond has been working on ballast, sub-ballasts and geotextiles under joint sponsorship since 1970.

He talked first about the development of a performance-based ballast specification which is used at CP Rail. He outlined how ballasts could be categorized, using laboratory tests of abrasion resistance and of toughness. These laboratory tests could be directly related to the expected service life of the ballasts; so it is truly a performance based ballast specification. Mr. Raymond cautioned that these predictions would have to be modified by the results of petrographic analysis which might show weak minerals in the ballasts. This is a unique specification and something that railways would be well served by incorporating into their practice.

Secondly he talked about sub-ballast specifications. He had specifications for filter sand to be used to protect ballast from intrusion of sub-grade particles, and for capping sands for use with geotextiles. Mr. Raymond has illustrated to us how extremely important it is to maintain some sort of sub-ballast to protect our ballast. We now have a specification for ballast which will ensure that it does not break down quickly or abrade quickly. Coupled with that, we have to have some sort of protection against the intrusion of sub-grade material which will foul the ballast.

Gerry Raymond then talked about geotextiles. His work has clarified a lot of the misconceptions that we have had about geotextiles. The purpose of geotextiles is to facilitate drainage and to separate and filtrate. They are not necessarily effective to improve the strength of the track structure. Geotextiles must remain free draining and be of a minimum weight to avoid abrasion by ballast particles. This is one of the problems that we had in early geotextile installations. Mr. Raymond has a minimum weight specification.

The installation of the geotextiles is very, very important. They must have a defined drainage path which must be able to transport water to a clean drainage ditch. Side slopes must be removed as they might dam this movement. Geotextiles must be installed to a minimum depth to protect against damage from tamping. Geotextiles cannot be used alone without a capping sand and sub-ballast. The benefits of geotextiles seem to be the ability to use a cheaper and less stringent specification for sub-ballast in areas where we are using the sub-ballast, or the ability to use native materials as opposed to transporting in sub-ballasts over longer distance. This certainly suggests the need for a rethinking of railway practices in general.

The important thing that comes out of this is that we must have a good sub-ballast specification, apply these sub-ballasts, and then use goetextiles in specific areas where local high quality sub-ballasts are not available.

**Summary of Track and Infrastructure Session**

During the question period most of the discussion was centered on rail grinding practice as we do it right now. We had some metalurgical opinion that the existing practice of heavy grinding of rail could be metalurgically damaging the upper surface of the rail. Dr. Kalousek got up and said that his technique of gentle grinding should solve that sort of problem. It is something that we have to look at more closely.

In closing, I think that we all felt that it was very useful that the researchers have been able to pursue these interests over extended periods of time and to have a commitment to a program rather than the "one year wonders" that railways tend to fund as a result of the ups and downs of railway budgets. Thank you very much.

P.J. DETMOLD: Thank you very much, Mike.

Do we have any questions or comments for Mike Roney about these track engineering topics?

R. MAUGHAN (Consultant): I was interested yesterday that someone mentioned steel ties. I've come to the conclusion in recent years that we should be looking again at steel ties for use in North America. As you probably know, B.C. Rail is looking at them seriously. Steel ties have a lot of advantages, particularly in term of life. They lend themselves to modern type fastenings and adjustments for different rail base widths. For light traffic lines, they could have economic benefits. Does the RAC Track Committee have that subject on their agenda?

M.D. RONEY: It is not on the agenda at the moment. There has been a lot of work done on alternate tie types, both railways having done fairly extensive analysis on the concrete tie option. I know it has been reported that there are certain problems with maintaining surface with steel ties because you have to ensure that you get the ballast packed in under the ties. They also don't seem to intersperse very well in the track. The battle will be won on first cost. If the steel tie comes in way under the concrete tie then that is the bottom line issue. Are you aware, Mr. Detmold, of any more interest in that area?

**P.J. DETMOLD:** No. I am aware of the interest on B.C. Rail but I am not aware of any more general interest. Are there any other comments on the general topic of steel ties?

**D.H. WALKINGTON (CP Rail):** The suggestion was that steel ties could be of interest on light traffic lines but even there, there are signal track circuits. I have the feeling that even ATCS will continue using track circuits for many, many purposes and that if this work is to be progressed one of the considerations would be how to provide track circuits? In the little experience that I did have with steel ties in Australia and in Europe, there was great concern over the extent of the damage in case of derailments rather than first cost. All steel ties had to be replaced in a case of derailment.

**M.D. RONEY:** Steel ties can be re-formed.

**D.H. WALKINGTON:** This is another cost. Don't forget the problem of track circuits.

**P.J. DETMOLD:** Any more comments on that subject?

**B. LONGSON:** Yes, I am familiar with the application of steel ties in Australia, a major application on a heavy haul railway, Mt. Newman Mining. I know they have had problems with level plus holding line and that this year they have contracted to put in 20,000 concrete ties. I think there is experience would-wide that suggests that steel ties are not the answer in a heavy haul .application, though I don't know whether that is a final statement. On secondary branch lines in Australia, I think there is still a good level of interest in steel ties.

**P.J. DETMOLD:** Are there any other points on this subjects? Are there any comments about rail grinding?

**M.D. RONEY:** There is certainly a question of what is called the systems approach to changes in rail and wheel profiles. We know that the mechanical departments of both CN and CP Rail found it necessary to change their wheel profile to accommodate the worn shape of the rails. Now the Engineering departments are finding it necessary to adopt a very defensive posture with regard to our rails, specifically because the Mechanical departments cannot keep their wheel profiles free of this false flange contact. The result is that we have had to change our profile of the rail. We have done some computer simulations with CIGGT to try to determine the best approach to this problem. In the long run, we do need a systems approach. We need some mechanical input to further developments and changes in rail profiles. Would someone from the Mechanical departments like to comment on that?

**K. ARREY:** (CN Rail Motive Power and Car Department) The problem is that the original wheel profiles that we were trying to develop were to conform as close as possible to what you would call average rail wear conditions. This certainly substantially reduced wheel wear. Now I suppose we are always going to live in this dilemma that when we reduce wear rate, then we end up exposing the same surface of metal to repeated cycles of stress, in which case you may be introducing a proneness to shelling or spalling. We have to skate in between the two limits to get optimum life on the rails and wheels.

P.J. DETMOLD: Do we have any more comments on that subjects?

F. BLADER (Consultant): I am a Consultant working for AAR on this very topic and therefore it is appropriate that I make a comment. I would just put in a plea for cooperation between the AAR efforts and any efforts going on in Canada, because, I think, only together are we going to solve any of these problems. We are going to create more problems than we solve if we start going off in different directions. I would like to make a couple of points. There are techniques available now whereby we can, with reasonable confidence, using analytic techniques, and backing them up with experiments to verify them, come up with optimal profiles for both the rail and the wheel, and I think we should try that. The complexity of this process comes about because of a number of factors like the amazing difference between profiles of particular rails. If one looks at 132 lb rail, or 136 lb rail, the difference so far as the tracking of a vehicle (and it is matched with the wheel) is enormous, and I cannot understand why the railway industry permits having such vastly different profiles on new rails. Of course, if one grinds the rails, then you can grind them to a common shape, and that is a significant factor these days. Then there is a small difference in terms of the cant angle that one particular railroad uses, which may in fact be better, but it really does not matter because one can cant the profiles to suit whatever is appropriate. Neverthless, these are complicating factors and there is a good case, I think, for a substantial piece of work aimed towards coming up with some universality in terms of wheel and rail profiles.

P.J. DETMOLD: Thank you very much Fred.

H. LIST: On the subject of the wheel/rail profile, I would like to also suggest that we are really not dealing with a rail profile or a wheel profile as such. We have to consider the fit of the wheel-set on the track, including flange-way clearance and wheel/rail angle of attack, which is a major factor in the wheel/rail interface. A complete system look at the problem has to include all these things.

P.J. DETMOLD: Thank you very much. I don't see anyone else here from the AAR who could speak for the track/train dynamics program.

Do we have more questions or points on this subject or any other subject to do with tracks?

In that case let us move on to the subject of freight cars and Mr. Kelly Arrey.

### 3.4 Summary of Technical Session #3 - Freight Cars

K. ARREY: Thank you Mr. Chairman. Yesterday there were seven interesting papers presented on the subject of freight cars; very timely topics because the industry will undergo pretty radical changes in the next few years. If we want to remain in business, I believe we are going to have to change some of our thinking.

## Train Dynamics Simulation

The first paper was presented by Mr. M. Kelley of DSL Dynamic Sciences Ltd. It was on Train Dynamics Simulation, the development of a computer simulation model that can predict, with reasonable accuracy, the magnitude of in-train forces, a timely tool for our industry. To remain competitive, we are faced with the introduction of new equipment such as articulated five-pack intermodal cars that have a gross weight of over 300 tons. This type of equipment even through heavy, can operate safely in long train consists of the same type of cars, because there is less slack, since you have fewer connections. The difficulty comes when the volume of traffic is not sufficient to operate unit trains of this type of car. Then it becomes necessary to mix these cars with conventional equipement. Now you have all the slack of a train of 100 or so standard 50' or 60' or whatever length of cars and if you add this car of 300 tons, where are you going to put it in that consist? Many railroads insist on putting these cars within the first 20 cars, of a mixed train if they are in small numbers.

The problem is that the transportation people like to marshall trains by destination and not by the type of car, its weight, etc. This results in extra costs to switch and put these cars in the right location. If you don't, if you for instance, put three or four of these on the rear end of a train consisting of 50, 60 or 70 conventional cars, a slack "run-out" could tear the train apart.

The industry needs this type of computer program, so that we will not have to experiment and have trains break apart before we can find out what we have to do. The author noted that the software program was in its testing phase and that it has been compared with similar programs. The program will be installed on NRC facilities in the near future so special research studies can be conducted.

P.J. DETMOLD: Are there any questions on this paper?

I certainly would like to make the point that this is an extremely important development which has gone to some extent unnoticed. We now do have this good dynamic program and I do hope that we can put together some major use for it. We waited for it for some time because we wanted a program that really did what was needed. But now we have it and I would be delighted to organize some major work for it.

## Train Resistance

K. ARREY: The next paper was presented by Mr. G.W. English of CIGGT. This CIGGT work on train resistance was funded by TDC. CN Rail cooperated and assisted in the collection of data. NRC assisted with the instrumentation of the trains.

Data from eight runs of CN Rail intermodal trains was recorded on analogue tape. The equipment consisted of older, single platform cars and low profile articulated 5-pack cars. The data recorded included speed, drawbar force, wind speed and direction, throttle position, train line brake pressure, locomotive independent brake pressure and track gradient. The data collected will allow an examination of the effects of bearings, track quality, trailer spacings and car configurations on train resistance.

This train resistance work is quite important to railways, which are faced with higher fuel cost, radically new car designs and higher operating speeds. It is becoming increasingly difficult to predict with accuracy the power and fuel needs for a specific operation. This test work will certainly result in better assessment of the elements of train resistance.

## Train Aerodynamics

This paper, by K.R. Cooper of NRC, is closely related to the presentation on train resistance. The work is a view of rail vehicle aerodynamics taken from the aerodynamicist's perspective. The objective of the work is to quantify potential improvements in energy conservation and/or trip time reduction through reduced aerodynamic drag as well as to present an overview of rail vehicle overturning due to wind action.

I have already commented on the importance of train resistance measurement work. The energy question, particularly, is decided by small differences in large resistance numbers and so requires accurate test results and realistic analysis of these results. The author commented on the application of wind tunnel measurements to this work.

I have been involved in the specification of railway cars for a long time. It is only in the last 10 years that air resistance has become important in freight car design. Much work is required in this area in order to economically judge the merits of reducing air resistance, and this will involve wind tunnel measurements. Until we can quantify the reduction in train resistance due to "streamlining" a rail vehicle, we cannot realistically recommend additional capital expense to reduce air resistance. In most cases, "streamlining" will increase capital costs.

An example of this is hopper car design. The Canadian car is designed with very clean interiors to facilitate unloading cargo, particularly in sub-zero temperatures, with or without the use of radiant heating to assist unloading. This results in car bracing being on the exterior of the car and higher air resistance. CN Rail is going to equip one hopper car with a second "skin" on the outside of the bracing posts as a test to reduce train resistance. Note that this will add about 1,500 lbs. to the weight of the car which reduces its load capacity. It also increases capital cost. The most difficult task will be to measure the reduction in train resistance due to this change. I wonder if this could be calculated with sufficient accuracy from a model?

## Frame-Braced Freight Car Truck

John Horwat of UTDC stated that the Frame-Braced Freight Car Truck program began in 1980 as an internal UTDC research program. It was expanded to a research, design and build test program in 1981 under the sponsorship of TDC and the Ontario Ministries of Transportation and Communications and Northern Affairs. The program resulted in a simple design of a new truck or retrofit parts which can be added to a conventional three-piece freight truck. The retrofit improves the dynamic stability and curving ability of the truck, increasing operating speed capability and reducing wheel, especially flange, wear. The test and research results were presented graphically to show their relationship. The author concluded by demonstrating a favourable cost/benefit analysis, the market situation and sales to date.

This is a welcome innovation in truck design. I would caution that it takes millions of car miles of service to fully demonstrate improved ride and favourable economics. Trucks are not sophisticated pieces of equipment and may not all perform equaly well; so you need a lot of statistics in order to get statistical reliability. This includes the life of the components added to the truck. Will they last for 200,000 miles, 300,000 miles or longer?

The extra cost of this truck is now of the order of $3,500 compared to standard trucks. This cost differential could increase if the retrofit parts have to be strengthened after extensive use.

Are there any questions on the Frame-Braced Freight Car Truck?

B. TAYLOR (CN Rail): This is not a question but a comment. One thing that concerned me greatly came up in the discussion period after the talk by Mr. Horwat, and that is welding on an area on the side frame which is generally recognized as an area where welding is prohibited. I hope that nobody leaves this conference thinking it is okay to weld in that area. I hope it is known that if welding is permitted in that area, the necessary testing is also required.

K. ARREY: I would like to comment on that point which has been discussed in our committee at the AAR. The rules right now do permit welding of castings but only by the foundry. If a foundry pours a casting and they have a defect in it, they can weld it in the tension member. However, the foundries are all approved and inspected. Every third year they must submit a sample of their casting and it goes through fatigue testing. UTDC seems to be saying that if you can allow it at the foundry, why do you not allow this welding elsewere. They did conduct fatigue tests at the Southern Railway Laboratory in Alexandria, Virginia, and the side frames did survive the test. I would like to know exactly what was done in the test, to make sure that it was duplicating what we think we would see in real life. The Southern Railway certainly did not want to put a large number of these trucks in service without having a fatigue test when they know that they are welding in that area. CN Rail would require fatigue tests under similar circumstances.

G. ALLEN (UTDC): We recognize the concern about welding of the side frames. I would like to say that UTDC is very interested in undertaking any further analysis or further testing to help confirm the safety of welding in that area. If anyone has any ideas on what tests should be carried out, I would be pleased to hear from you.

P.J. DETMOLD: Any more questions on trucks? No? Then will you please proceed Kelly.

### Radial Axle Freight Car Truck Tests

V. Khatchadourian of CP Rail presented the results of these tests.

The Research and Development Department of CP Rail has conducted in-service evaluation tests on two types of radial truck, the Barber Scheffel and the DR-2 self-steering truck. Both trucks were introduced in 1982 and the Barber Scheffel has accumulated approximately 400,000 miles in revenue service. The results of these tests are very encouraging.

Wheel wear measurements were carried out on these trucks, and the results of truck tear-down inspections presented. The results of fatigue testing of the steering arms for the DR-2 truck were also presented.

The UTDC frame-braced 100-ton and the 70-ton rigidized elasto cushion trucks were evaluated for high speed stability and curving performance in 1984 and 1985.

In 1986, CP Rail introduced the first train sets of coal cars equipped with Barber Radial and DR-2 trucks into revenue service. The proposed 1986 test program for these trucks was presented.

I would caution tht these tests are based on a small sample of cars and will not give statistical reliability. The continuing monitoring of the performance of 60 car sets of each radial truck will provide important data to determine the economic justification for these premium trucks, $6,000-$8,000 per car set.

P.J. DETMOLD: May we have your questions and comments on this subjects.

H. LIST (Consultant): As we have Kelly here representing CN Rail, I would like to hear about CN Rail's experience with its many DR-1 cars.

K. ARREY: CN Rail has approximately 750 cars equipped with DR-1 trucks in service and these cars have reduced wheel wear. That is the only characteristic we can measure. Unfortunately, we have no measure of what they are doing to the rail, but you can surmise that if you reduce wheel wear, you must be reducing rail wear at least as much or more, because the rail does not suffer additional wear of a brake shoe on it.

We have been a little disappointed with the first 100 of these cars which have had 3-400,00 miles of service. Those cars have had a fair number of the pads changed out which is a cost not taken into consideration in the original economics. We had expected that these components would last a million or more miles before we spent this kind of money. It will be interesting to see if the newer 650 cars run into the same problem at this mileage. The larger sample is required to get statistical reliability for pad life, - or any other truck characteristic.

P.J. DETMOLD: Do we have any more questions on the subject of testing radial trucks? No? Then will you please proceed Kelly.

## Tank Car Thermal Model

K. ARREY: Dr. A.M. Birk of Davis Engineering Ltd., Ottawa, described "A Computer Model of a Rail Tank Car Exposed to External Fire Impingement". This is a model to simulate what happens to a tank car and its lading in an external fire. The model has been developed to study the effectiveness of a variety of thermal protection systems for protecting against the risk of thermally induced tank rupture. The work is sponsored by TDC.

The computer model can simulate a rail tank car, or any long cylindrical tank, filled with light petroleum products, such as propane and propylene. The model can simulate both an engulfing type or torch type fire. Tank roll and pitch can be accounted for.

The model can predict tank internal pressure, tank wall temperature distributions, mean lading temperatures, relief valve flow rates, fluid level, tank wall stress conditions, and tank failure, all as functions of time from fire ignition. The computer model has been validated using available experimental data from full and fifth-scale fire tests conducted on tank cars filled with propane.

Thermal protection systems that can be simulated at present include thermal insulation, thermal radiation shielding, internal thermal protection, fusible plug pressure relief devices, and pressure relief valves. The above systems can be modeled separately, or in any combination.

The model can be used to plot characteristics such as mean lading temperature against time to follow the progress of the fire to the point when the tank car wall will fail. This work will help car designers to determine what can be done with, say, insulation, to reduce the possibility of a major explosion.

Are there any questions or comments on this work?

## High Productivity Integral Train

Mr. D.N. Ferrance of Transportation Technology Ltd. opened by saying that the Urban Transportation Development Corporation (UTDC) is responding to the AAR's invitation for integral train proposals. The AAR specification requires a 50% reduction in the cost of intermodal deliveries and significant improvements in service. To meet this specification, which is to move an intermodal "box" from A to B at half of present cost, requires radical equipement technology, as well as methods of operation and organization.

The present restrictions on equipement for interchange service have been set aside to permit radical design changes. The proposed equipment design is a series of lightweight monocoque structure units, each 50' long, 10' wide and 10' high. These units would be supported by two single axles, one of which would be coupled to an AC motor for propulsion and primary braking. Slackless, resilient ball joints would be used to couple the units into mini-trains. The train, looking like a tunnel, would have passenger train air resistance and speed characteristics and be powered by an underslung, proven truck engine coupled to an alternator. Road control would be from a self-propelled crew module attached to the leading end of the train.

The train is designed to carry intermodal bulk or mixed cargo. Cargo would be moved through the mini-train from either end, possibly using pulleys and air suspensions.

This design is based on an in-depth analysis of operating costs. I would say that the idea is good. The concept and the train will require a lot of testing.

P.J. DETMOLD: Do we have any questions on HPIT? I suggest we break for coffee and reconvene at about 10:50.

COFFEE BREAK

P.J. DETMOLD: Gentlement, let's reconvene. I have the pleasure to call Doug Walkington for the last of our four reports.

## 3.5 Summary of Technical Session #4 - Signalling and Communications

D.H. Walkington: Mr. Chairman, we had five excellent papers yesterday at the session on signalling and communications. I enjoyed them all. They were all extremely useful papers and showed some of the real benefits that have come out of the ARFP program.

I will base my review on the abstracts of the presentations.

### End of Train Monitoring

Dr. R.J. Pomery of DSL Dynamic Sciences Ltd., Vancouver, made this presentation. He began by noting that economic pressure in the railroad industry has resulted in a search for ways to reduce operating cost. As a direct result, technology has been developed in the form of rear-of-train telemetry equipment. A Sense and Transmit Unit mounted on the trailing coupler of the last car conveys brake pipe air pressure and motion status to a Receiver Display unit in the locomotive cab. A manually-initiated odometer in the locomotive provides a measurement of distance travelled past a point. Equipment embodying the capabilities outlined above has been in operational service in the United States since July, 1984, and has been successfully tested and demonstrated in Canada. A recent enhancement, developed for the Canadian market, imcorporates the capability to apply emergency braking from the rear of the train, initiated in the locomotive cab.

P.J. DETMOLD: I think really you should review all five subjects and then have one question session.

### LED Signal Technology

The second presentation on Light Emitting Diode Signal Technology was given by J. Lougheed of Davis Engineering Ltd., Ottawa.

This presentation began by explaining the fundamental optical and visual properties of long-range wayside signals, and how TDC has been supporting technology to improve reliability and safety. The existing signals utilize incandescent lamps as the light source, interposing red, yellow or green filters by use of an electrically driven mechanism. The LED project set out to eliminate both lamp burn-out and moving parts found in the existing signals, through the use of high brightness LED's of each colour, electronically switched.

After reviewing the current state of LED technology, its advantages and disadvantages compared to incandescent lamps, the research approach taken by Davis was explained. It was emphasized that the optical treatment of LED's is different than that for traditional point sources if maximum output is needed, and the two approaches were described.

Prototype LED inserts for retrofitting existing signals were delivered to TDC at the end of the project. They provide 800 meter range in bright sunlight, exceeding the minimum requirement but falling short of complete equivalence with the existing signals. Far greater range is obtainable with red LED's but yellow and green lag because the individual devices are less bright. The best green currently available is deficient in blue according to the present specifications, although tests by individuals with normal colour vision were satisfactory.

Mr. Lougheed demonstrated one LED array, and briefly mentioned some spin-off products being introduced to the railways. He also discussed a new project on enhanced grade crossing signals using LED's and showed the model of early concepts.

### Container Terminal Simulation Model

The next paper was not on signalling and communications. It was to do with simulation and it fitted in very well with the session. Container Terminal Simulation Model, by Ian Grunwell and Paul Rossi of CN, was received extremely well and a lot of questions were asked.

The Container Terminal Simulation is a computer simulation of major operations of an inland container terminal: inbound train arrivals and unloading, outbound train departures and loading, storage of containers arriving by train or truck, customer pick-up of containers. The model consists of a batch simulation and a graphical postprocessor. The simulation evaluates plant designs, equipment trade-offs and yard operating policies. The model was used in the design of the CN Montreal container facility and is currently being used to assess the effect that changes in traffic levels would have in yard operations for the container facilities in both Toronto and Montreal.

## B.C. Rail's Advanced Train Control System

Mr. B.E. Mrazak's presentation commenced with a brief description of B.C. Rail's endeavours since the early 1970's to implement the Location, Identification and Control (LIC) system. The main technical reasons why LIC was not successful were explained, in particular the inadequacy of the UHF data communications protocol.

The second part of the presentation described the joint efforts in the past few years of the Railway Association of Canada and the Association of American Railroads to establish standards for Advanced Train Control Systems (ATCS). This was followed by a description of B.C. Rail's recent efforts to implement an ATCS on the North Vancouver-Squamish subdivision utilizing those components of LIC which are ATCS compatible and discarding those that are not.

We were provided with an overview of the B.C. Rail ATCS. All the major components of the system were identified and their functions described. A detailed description of the data communications protocol was given explaining how it has overcome the problems encountered in the past. There was a description of the locomotive equipment and particularly the manner in which the main processor interfaces with the processors associated with the various peripheral devices. The graphics used with the cab display unit were highlighted.

This was a very good introduction to the next presentation on the ATCS project.

## Advanced Train Control System Project

Earl Baynton of CP Rail told us that early in this decade, the Railway Advisory Committee, now RAB, began fostering the idea that existing technology, particularly in the fields of micro-processing and communications, presented the means for significant improvement in the area of train control. Thus ATCS was born. The objectives of that infant project fell into three main categories: Safety, Economy and Improved Operations.

ATCS operating requirements were published in April of 1984. The project was granted immediate joint sponsorship by the Railway Association of Canada and the Association of American Railroads. The working group that wrote the requirements was asked to continue as a steering committee and Mr. P.J. Detmold was named General Manager. Eleven support and monitoring groups were established, using people that are highly skilled and respected in their fields. The initial systems engineering work was to identify and evaluate appropriate technologies, consider how they could best be adapted to the purposes of ATCS, and determine how they might be integrated into a practical systems architecture. The contract for this work was signed in January, 1985, with a consortium of three companies, ARINC Research Corp.

of Annapolis, MD., Transportation and Distribution Associates Inc. of Philadelphia, PA., and Lapp Hancock Associates Ltd., communications specialists, from Ottawa, Ontario. Representatives of even more railways joined the steering committee along with a senior representative of the AAR Research and Test department.

At the present time, committees of railway and supply company representatives are writing detailed specifications for each functional component. The underlying principal of component specifications will be the "form-fit function" concept. Mr. Baynton then completed a review of the current status of the work and that planned for the near future. He noted that some products are already being offered for tests, on the expectation that they will meet or can be readily adapted to meet ATCS specification. Several railroads are actively considering these proposals expecting that any experience gained will be mutually beneficial and perhaps expedite component development.

**Summary of Signalling and Communications Session**

There was a good discussion of all papers. I personally would like to thank all of the authors and the speakers who put so much effort into these papers. I know it takes a lot of work and they really do deserve a lot of credit for these presentations. The high quality and interest in these five Signalling and Communications papers, and in the others that I heard, was verified by the number and the depth of the questions that were asked. Credit should also be given to the RAB and TDC; (I am not on the RAB). I think that credit must be given to those two bodies for putting on this seminar and for the ongoing work.

P.J. DETMOLD: Thank you very much Doug.

Do we have any questions? In that case, let's proceed in the following sequence: first of all I would like to invite Steve Cavanaugh to tell us a little more about what they have been doing with locomotive 4744, and then we will move into the final discussion of this meeting.

S.D. CAVANAUGH: Thank you Mr. Chairman. To avoid pre-empting the paper that we are going to give this year at the Heavy Haul Conference in October, I guess the best thing is to give you a brief run-down of the total program and what is involved.

The program was conceived for the purpose of evaluation of AC traction equipment in a North-American freight environment. The program partners consist of CP Rail as the program managers, (we provided the unit for retrofit in the program), Brown Boveri Canada (BBC), the electrical equipment supplier, and Bombardier, who are the locomotive advisors on the project. The unit itself is CP 4744, and was originally constructed by Bombardier in 1970, if I recall correctly. It is a six axle, 4,000 horsepower traction unit with six motorized axles in its original DC configuration. We converted it to four AC motors in an A-1-A type configuration, that is, the centre axle on each truck is an idler axle. It still retains its 4,000 horse power rating; therefore each of the AC motors now is powered at

1,000 horsepower per motor. The unit was brought into CP's Angus shop in 1984 and retrofitted with the AC equipement.

It came out of Angus shops in December 1984. Last year, 1985, was pretty much devoted to commissioning tests. We did functional tests on the unit, adhesion testing, some lifting tests, as well as to verify the dynamic brake characteristics of the unit. These tests are quite lengthy. They involve the use of up to two and three other units with extended range dynamic brake in the consist to act as drag for the AC unit. Some of the preliminary results that we have seen by way of the lifting test show astonishing differences between an AC unit and a DC unit. We have seen starting forces up to 92 or 93,000 lbs. on four 65,000 lb. axles, much greater than possible with a similar DC unit with the wheel slip protection. The unit can do that for extended periods of time without worry of flashing the motors or stall burns or what have you.

As of January 1st, 1986, we have put the unit into service. It is operating between Montreal wharf and CP's Cote St. Luc yard. On that run there is a 1.6% gradient - Hochelaga - and we have purposely at times isolated the other units in the consist and, depending on the trailing tonnage, let 4744 do all the work. Again, depending on the tonnage, some of the runs that we have done up that hill with a train have balanced out at about 3 or 4 miles an hour. The unit has spent 45 to 50 minutes at 4 miles an hour coming up that grade with no trouble at all. The results of the tests that we have seen have been very encouraging. As of next week we are assigning 4744 to Montreal-Quebec City in regular revenue service.

I think that pretty well sums it up and I invite you all to come out to Vancouver to hear the paper in October.

P.J. DETMOLD: I think I should make it clear that I did not initiate that commercial for the Heavy Haul Conference, even though it is under similar management. Now let us begin the final discussion.

### 3.6 Discussion of Augmented Rail Freight Transportion R&D Program

P.J. DETMOLD: I think perhaps I could assist in the matter by listing some of the questions that you might wish to consider. In doing so, I don't want to limit the options in any way. Please make any remark you wish. I think there is only one rule of the game that I have found on such occasions is generally helpful, and that is when a subjects is entered, we will not enter another subject until we are through with the first. I will take questions on the subject up until there are no more, and hold other questions over.

I make the questions about four. Is cooperative research worthwhile? Has the program been successful? What changes in the program would it now be appropriate to make? What kinds of projects? I think it was Mike who said "one year wonders" or major "big bang" efforts? Should there be major railway supplier cooperative programs? And finally, what specific programs should we do? After all that is really what matters. I would like to start by inviting Ted Rudback to make his own comments on how the program has gone and then I'll open it for general discussion.

N.E. RUDBACK (TDC): Thank you Peter. I have just been sitting here and I think, doing what perhaps is appropriate for a Transport Canada official at this point in time - a lot of listening as railway and technical people discuss the work that has been done and the results achieved - and it seems to be impressive. The program is a result of the Railway Advisory Board and their initiative. It represents a concerted effort to work cooperatively. We see competing railways and suppliers working together to solve common problems, and I think that results in benefit to everyone. Some of the problems affect Transport Canada and our involvement in them to act as a catalyst, I would hope, has helped the process. The program has involved not just the railways and government but also the supply industry. The traditional suppliers, and, very importantly also some of the non-traditional suppliers, challenged us with new ideas and new ways of doing things. At this point in time I think it is clear that some of their ideas are very good and are starting to be implemented. One of the things that has made it work, is the fact that the railways have taken the initiative in trying to define the problems and have signalled their priorities to us in government and industry in such a way that industry has been able to address the problems and come up with solutions. What has helped in the process too, is that the railways and Transport Canada have made a commitment to R&D, a fairly stable commitment over the last few years. In time of budgetary constraint this gets more and more difficult to maintain, but I hope we will be able to maintain an initiative of this sort.

The program resulted from the "Rail Research 2000" that was put together by the Rail Advisory Board and while it said 2000 it was produced 5 years ago, and I am sure Peter, who was the main instigator, never expected that it would remain unchanged until the year 2000. Now that we have the experience of the first five years, I think it is appropriate to look at the results and to look ahead at where we need to go. In this process the more we learn, the more we realize at times how much we really need to know; so I think that Peter has touched upon the key elements of some of the questions that we ought to address here today. I think we ought to discuss as well, where we are going technically and where we are going in terms of how we work together, how this process has worked, and how we see it working into the future.

P.J. DETMOLD: Thank you very much Ted. Now, who would like to start the ball rolling? It is free for everybody. Who would like to make some kind of sugestion or comment? I have an offer from Bill Moore Ede.

W. MOORE EDE (CN Rail): Thank you Mr. Chairman. May I start by congratulating the chairmen of the technical sessions on the fine summaries they gave of yesterday's papers, thereby allowing us to get a good understanding of some of the issues that were discussed in sessions that we were not able to attend. Their work is much appreciated.

Mr. Chairman, if I could address your first question first and then go on to ask a couple of questions, I would like to do that. Your first question was "Is cooperative research worthwhile?" From our own experience in the Advanced Train Control System project, I would have to say yes, cooperative research, cooperative effort in research and development is worthwhile.

The ATCS project is between the railways as users and the suppliers. I think both sides see the benefits of cooperation, otherwise the work would not be carried out with as much enthusiasm. There are three railways in Canada involved in the project as well as a number of railroads in the United States and there are a lot of suppliers involved. A number of tests are now being carried out, specifically geared at various elements of ATCS: data link tests, transponder tests, test on displays, tests on more general communications problems. This is also a cooperative effort in terms of railways sharing their information and the results of their tests as it becomes available.

Now I would like to introduce several relevant questions, preceeded by this observation. In the various discussions that we has yesterday, I did not hear anyone mention the cost of doing the research, or the ultimate level of benefits to be gained as a result of the research. This leads me to these questions. How much of this research would not have been done without government funding? (It may be that the research would have been done but it may have taken longer.)

How much of the research would not have happened if there were not government funding? If the end user of the research and the suppliers jointly cannot see enough benefits to fund the research, what are the arguments for doing such research?. If we can't measure the benefits before we start, then should we be doing it?

I have one other question on a different subject. When an area of research or development is needed where the railways may not have specific knowledge of where to go to get particular skills, it would be useful to have a current directory of skills and companies from which to obtain that sort of information. Does TDC maintain such a directory?

P.J. DETMOLD: Thank you Bill. Who would like to add to this subject?

N.E. RUDBACK: Bill, I think you have raised a number of very good points. One of them is one of my favourite subjects, the cost and benefits of research and development. We can identify the cost, I think, fairly readily. What is difficult to identify are the benefits, because the benefits are long-term and are indirect as well as being direct. If you get a direct spin-off immediately you can probably measure that benefit but in a lot of cases, it is indirect.

For example, the ATCS project resulted from our program. Would it have happened without that? At some point in time it would have, when, how, - those are things that it is very hard to put a dollar value on. I say to that question, that the benefits that you achieve are best evaluated by management judgment and experience, and that determines how much you put into R&D in what area. I will turn that around to some extent and say that we are managers here and we have to use our judgment and experience. If anyone else wants to comment on that, I hope they will, because that is part of what we're trying to assess this morning. I don't think you can sit down and quantify all of the benefits we might receive; and we probably don't even know all of them yet. By the time we do know them all and can do that, no one will have any interest in them anyway, so we just have to use our experience and judgment at this point in time.

With respect to sources of knowledge, TDC does maintain a Transportation Research Library which covers the whole transportation field and offers good facilities. It is second to none in Canada. In terms of directories of expertise, I think there are people in TDC as well as people in the railways, DRIE and NRC that know this. The only directory that I know of on expertise is one maintained by NRC, however it may only touch on government. Could anyone from NRC comment on this subject?

P.J. DETMOLD: I would make a comment on this subject, and in doing so, I would like to put on my ATCS hat just for a minute. It does seem to me that there is always a difficulty in getting a project started. I think that Bill Moore Ede would agree with me that as we have gone along with ATCS, benefits emerge that we did not think of in the first place, and things that we thought might be good have proven to be not quite so good. You do, somehow, need to nurture the "child" before it earns its living. I think this is really the question which we are looking at. How do you do that? If Bill and I had gone around this industry at senior management level when ATCS was just beginning and conducted a vote on whether or not to continue ATCS, I am certainly not confident that we would have received support to continue the project. The problem seems to be, and I am not doing this to express my own views so much as to crystallize the question, how do you get the thing going in the first stage?

Other industries do it in different ways. The airlines, going back to the early thirties, used to commission aircraft. I think it was American Airlines that commissioned the DC-3 and Trans World Airlines, the DC-2. That started the move going and it has always been their habit. In the trucking industry (I really don't know much about it), I believe that there are enough truck lines that it must work like the automobile industry in which models come out and compete with each other. There is not really much need for some truck line to go and say that it wants whatever it is. Somehow in the rail industry there seems to be some characteristic of working that is different from any other. Do we go on like that, -or do we try and break out of it? ATCS shows we can break out of it. The High Productivity Integral Train shows us that maybe we can break out of it more widely. Have you any comments on that?

N.E. RUDBACK: I have one that is relevant on the subject. I know that I am breaking my rule about being just a good listener this morning, but I think that the Canadian situation is a little bit different. In Europe, State operated railways are working "hand-in-glove" with suppliers to develop specific products and systems for their applications. In the United States the free enterprise system is at work, - you have not only very large railways there, but very large supplier industries that can make large investments in R&D. In Canada we have large railways and a good market but the industrial base is not as large so we don't have the full advantages of the sort of free enterprise that we see in the United States, and we are not supporting our supply industry the way the State railways do in Europe. How do we work in this sort of environment?

Bill, one of your questions has to do with need for government support for research. That is a very valid question for discussion here today, particularly as Transport Canada and all government departments are feeling a financial squeeze and are seriously looking at their budgets and asking whether the investment is worthwhile.

P.J. DETMOLD: Well, you are all looking very thoughtful. Who will be the next speaker?

K. ARREY: I would like to comment by giving a good example of what has happened already and where governement assistance could be required. The example is about self-steering trucks, the DR-1, DR-2 and the Barber Scheffel. The companies that produce these trucks have been selling them for over 10 years. If you count the number of trucks that have been sold, I don't see how there can be any return on their investment. These companies have spent a lot of money on these trucks and still have not realised a market for them. This could happen in many areas, unless the railway involves itself and says, yes, this is what is wanted, and is willing to pay a premium for it. Twenty-five years ago, the same thing happened when the cushion underframe was developed. The premium was about $5,000 per car. The railways would go to manufacturers and ask them to make it for the same price as the draft gear, which was only about $200. For the manufacturer the task was hopeless. It was only when the railway's customers said unless you put cushion underframes on we are not going to ship by rail, that cushion underframes came into widespread use.

M. PAYNE (Bombardier): I have been involved in this program for some time. We have had some cost overruns so we really can't say how much it is really going to cost in the long term.

With respect to benefits to the railways, we developed the Bombardier single cylinder research engine with the help of TDC. It was intended for diesel engine research. It was not expected to be sold. One engine was sold to the AAR and is now used to test diesel lubricating oil, replacing a two-cylinder EMD 567-B engine. This more realistically tests lubricating oils and the various additives because this engine produces 400 horsepower at 1500 rpm compared to about 150 horsepower for the EMD engine. This engine is also used to simulate a 12 cylinder GE engine with the same bore and stroke to save testing fuel. These things have come out of this program which were not there in the beginning. Thank you.

P.J. DETMOLD: Thank you very much.

HENRY VALLE (DSL): I think that Ted Rudback explained the R&D situation quite clearly. We are faced with competition from Europe where the state railways work hand in glove with their manufacturers. In the United States we have the free enterprise system, and, of course, here we are smaller. I guess DSL Dynamic Sciences Ltd. fits into the category of one of the newer supply companies. The process of a small company trying to work from our own bootstraps has been a very difficult undertaking. There has been substantial support from the government for most of the products that we have developed. The company is now reaching the stage where it is selling a lot of these products competitively in the market place on a world-wide scale. In the United States the Digitaire end-of-train monitor is being sold in large quantities. We have just sold a full-scale training simulator to the Swedish State Railway. I think this progress indicates that the money that the government is putting into R&D here is providing practical benefits not only for the companies but also to the railroads. I would heartily support the idea that there has to be some measure of government support to encourage R&D.

P.J. DETMOLD: Thank you Henry, do we have any more opinions on this general subject?

I think that we have reached a conclusion that the process of development does not seem to happen in the railroad industry. I don't believe that one can distinguish between Canada and United States, as there seems to be much the same conditions in the industry on both sides of the border. We also seem to have reached the conclusion that the process needs some sort of nurturing of an undisclosed kind to get it moving. I very strongly agree with Bill Moorede's point that the 'child' has got to demonstrate its health and ability to earn its living from an early stage. We have the problem of how do we get to that stage? I am not sure that we are going to make any further progress in this area today. Without limiting your comments, I suggest that we should think about some of the areas that might qualify for assistance in the remaining few minutes. Would somebody like to suggest some of the major areas for research that we might consider for this kind of treatment?

I do note that we had one proposal this morning for a major wheel/rail joint profile study. I am not sure how we would integrate that within the enormous amount of work already done in the track/train dynamics program and at Pueblo, Colorado. Our work should be very closely coordinated with that work. The other suggestion that comes from yesterday's technical sessions was that we should have a better look at longtitudinal train forces. I know that John Punwani of the AAR did an enormous amount of work on this subject a few years ago; I don't recall that it really came to any conclusions, in that the study was never totally completed. Now that we have this new model (Freight Cars-Train Dynamics Simulation) almost ready to work, is that an area to get into? I am just tossing out a couple of ideas that appeal to me. Can we make a short list of things we ought to do. I have got two.

W.H. ELMARAGHY (University of Western Ontario): I have worked for 15 years on the design of trucks for freight and passenger equipment and would like to raise the possibility of new work in that area. A lot of funding from TDC, and efforts from the railways and others, are directed at improving the performance of the three-piece freight truck. This includes bracing and adding things to it for better performance in terms of stability and curving. Kelly Arrey stated that the three-piece freight truck has been around for many, many years, and has been improved during that time. Is there a need for a new freight truck instead of trying to improve the existing one? The wheel has also been around for a long time, but with new tools for design and analysis, some companies have recently re-designed the wheel. Hawker Siddeley has done a lot of work lately with the AAR and came up with new wheel designs which are substantially improved in terms of performance and resistance to thermo failures. I repeat my question, is there a need for a new freight truck? Is that a project that is worthwhile working on now from the ground up? In carrying out such a project, all of the new information that has come from many other projects including the track/train dynamics project, would be used.

P.J. DETMOLD: Thank you very much. It is a very good question. If you compared the cost of rail equipment maintenance with the dollars spent on research, I suspect that the wheel and brake system would be a deserving candidate for a little more funding. I did this exercise a little while ago for one railway and certainly there is a case to be made in that area. Are there any further comments on this point?

K. ARREY: I might add that the wheels and brakes, the running components of the truck, account for approximately 75% of the maintenance cost of the car. A conventional truck carries 100 ton loads. It is a pretty sturdy piece of equipment, and yet this truck sells for a little over a dollar a pound. It has evolved over such a long period of time that it is very hard to beat cost-wise. This does not exclude inventing anything else. If, however, you come up with a new truck that has, say, in-board bearings, instead of out-board bearings, you now need to stock different wheel sets at repair points as replacements. If the new truck is in interchange service, all railways must stock the different wheel sets, a costly addition to maintenance stock. That is why I get back to that high productivity integral train. You only run it where you want to run it, and do not interchange it with anybody else, allowing much more scope for innovation. Is TDC backing integral train operations?

P.J. DETMOLD: I believe so.

N.E. RUDBACK: We have supported the conceptual design of the HPIT, but I think it has to be put to the test and we are putting this one to the test right now. Unless we see railway support for it, in terms of someone willing to buy it and test it, we aren't putting any more money into it. If that happens, we will still question whether we have money to put into it, but certainly that is the first criteria.

K. ARREY: As I said earlier, until a railway backs something like that, it is pretty hard for anybody else to support it, including manufacturers.

N.E. RUDBACK: Exactly.

M. AVNI (TDC): Thank you Mr. Chairman. I would like to raise an item for possible research in the area of data communications. We now face a whole series of projects that deal with train-to-wayside and end-of-train to end-of-train data communications. Some of them are presented in this seminar. This work includes the end-of-train monitor, the remotely operated power switch, the work on B.C. Rail.

The statistical characteristics of the communication channels used in all of this work are borrowed from the mobile automotive world, which is not necessarily identical to that of the railway. Therefore, the solutions applied to railway problems, usually borrowed from the mobile automotive world, are not necessarily optimal for railway problems. I wonder if you would agree that there is a good benefit in trying to find the specific statistics of these channels, to try to get more familiar with the noise problems on these channels. The objective would be to better define what should be the modem, what should be the error detection, error correction mechanisms that should be applied against these specific channels. These problems will become of even more importance as data communication channels become vital parts of railway control systems. I realize that some of this work is already identified in the ATCS family of problems, and perhaps that is another incentive to get into this area of research.

P.J. DETMOLD: I would like to comment and then ask Bill Moore Ede if he would like to add to what I say. I really see two different questions here. One is the design of communications protocols which, as you observed, ATCS is very vitally involved in. ATCS has to get this one right. The other point is about the frequencies and their characteristics. Our principal concern is getting permission to use them. We have a very limited range of frequencies in the United States, and to a lesser extent in Canada. Our principal problem is getting exclusive use of some of them - if possible the same ones on both sides of the border-so that we can run trains through without any communication difficulties. Bill, would you please add your comments.

M. AVNI: Before Bill answers, I would like to emphasize that my suggestion does not deal with protocols or necessarily with frequencies but rather with the statistical characterization of the channels.

P.J. DETMOLD: Yes I did understand that. My answer was intended to include error correction techniques which ATCS systems engineers are developing for us. Bill?

W. MOORE-EDE: Thank you Mr. Chairman. As you suggested I think that there are two aspects. I know that a study has been recently prepared (I think at Carleton University), that looks at the characteristics of the various frequency bands with respect to errors and a wide variety of physical and environmental conditions. This information is being used by the ATCS project. This month this subject will come under intense discussion by the supply industry. We're counting on the expertise of those who actually have to provide the hardware for communications to give us good answers. They have a tremendous stake in the outcome of this work. Many of these issues are going to have to be resolved within the next two to three months if we are going to be able to get ATCS going within a reasonable time frame. The whole specification process is on-going and the railways themselves are already undertaking tests. I know of one test that was going on last month in the United States, looking at communications outside the urban area. It was extremely successful. I know of two other tests. B.C. Rail is doing some work, and CN Rail is planning some also. There is a lot of work on-going right now and we expect to have a fairly early answer on some of the issues that you raised.

P.J. DETMOLD: Bill, do you see any particular area for research of the more fundamental kind rather than the testing you described? Do you see any areas that you think should be covered perhaps at the University level?

W. MOORE-EDE: I don't know of any right now that have been raised as particular issues that have to be resolved. Clearly ATCS must get a handle on the protocols. It may be that if we end up with two or three competing protocols, that some sort of evaluation will have to be made as to the relative benefits of each, and that may be something that will come out in the next month or two.

P.J. DETMOLD: I see, thank you. Do I have another question?

K. TIKKANEN (RTC): Mr. Chairman, let me get in a few words here from the safety regulator's perspective. We are very interested in the highway/railway crossing interface as one of the safety areas. Although there is considerable activity in looking at systems and means to reduce crossing accidents, we would be happy to see any research initiative that would further efforts in that direction.

You mentioned longtitudinal forces in trains. That is another area of interest for those of us who are involved in accident investigations. Simulation methods would tell us something about these forces and how they translate into rail roll-overs and other phenomena that could be involved in accidents.

I might add that the matter of safety is also of great interest to politicians, and the public at large. We will probably be hearing a lot about safety in the months to come. I don't see it diminishing. If you can demonstrate the linkage between safety and some of the work that you are now doing and will be doing, between safety and the other productivity elements that you are striving for in your research, it would make it easier for people like Mr. Rudback and others in government to make a case for continued government funding.

P.J. DETMOLD: Thank you. Here is another question. Is there specifically safety research which does not get funded because it does not have any alternative commercial side. I think our experience in ATCS is that you really get safety, productivity, and better service all rolled into one package. There are, however, some areas like crossing safety where there is less of a commercial return. Is there something we should be doing there? Do you propose any specific research we should add to the list on the grounds that it won't get funded because it is not financially self-sustaining?

M.D. RONEY: One project which might fall into that category is some way of non-destructively measuring stresses in continuous welded rail. We still get some unexplained buckling in continuous welded rails and a lot of pull-aparts. Some of it relates to the fact that stresses in the rail change as a result of vibrations from trains, from rail plugs that may be put in, and from defective rail. It is definitely a far bigger job that we are capable of promoting ourselves within the railway and it does definitely have a safety slant. I am not aware of any efforts to successfully measure the stresses in continuous welded rail, but I know we, at CP Rail, certainly have a big interest in it. Can anyone here comment on possible successes in that area?

W. MOORE-EDE: I would just like to echo what Mike is saying. The measurement of the internal stresses in the rail is one of the operating requirements of ATCS. This work would have North American-wide applicability.

P.J. DETMOLD: Do we have any more comments on the general subject of safety?

C. GANNETT (U.S. DOT): We are trying to tie on to the coattails of the military in NASA in the area of non-destructive testing, and there are a lot of advances going on. I don't think we have arrived at solutions to non-destructive testing of rail, wheels, or bearings. It certainly is an area that requires a lot of research and we are giving it the most attention we can.

P.J. DETMOLD: Thank you very much. From this discussion, it certainly seems to me that we need a link between people who are doing what one used to call pure research, research of a non-specific kind, and those who are developing specific commercial applications. Is that an area in which we should be doing more? In ATCS, as Bill Moore Ede has said, we have had a few quite important issues in which we really need some research information. The reliability of transponders is an obvious example, though our information is that you can get some highly reliable ones. With respect to track circuits used to measure rail security rather than location of trains, there are some new circuits being developed, I believe, in Britain. Why should it only be in Britain? We do perhaps need a stronger link between the user industry and the researchers of this world. I don't mean developers doing research, I mean people who are true researchers in the sense that they don't know the result they are looking for when they do the work. I see So'n Lamson would like to say something.

S. LAMSON(CIGGT): I would like to add a point on this subject. One of the important links that we need between research and the users is some way to help railways to identify the benefits of research. The issue of wood ties is a very good example. We have done a lot of research and improvement in the area of rail and ballast but there has not been much work done in the area of wood ties. The reason appears to be that wood ties last a long time and are quite cheap. Mike Roney indicated earlier that it would be very difficult to justify even a small investment for improving the performance of wood ties. If you look into it, it is common knowledge that wood ties give rise to gauge widening. Gauge widening makes a significant contribution to the degradation of the rails, especially the low rail. In fact, it is one of the reasons for grinding the low rail. So we know that the use of wood ties results in rail maintenance costs. We also know that gauge widening and the related contact between wheel and rail on the low rail give rise to safety problems. You may have derailments. So even though wood ties last a long time, it may not be the only factor that prevents us from investing money into improving wood ties. On the other hand, some railways found it possible to justify a major investment in tie cost by going to concrete ties. If we can justify quite a large investment in concrete ties, perhaps this reasoning can be used to justify research to improve the wood tie. We need some convenient ways for researchers to help railroad management to quickly and simply look at the approximate cost trade-offs between research and research investment. It would seem to be very helpful in the development of a research program for the improvement of the whole track structure.

P.J. DETMOLD: Thank you So'n. Does anybody want to have a word on this subject?

D.H. WALKINGTON: This is not about wood ties but about the concept of collaboration and benefits and costs, that we need better cooperation between the researchers and the users. I think we should be clear on who the users are. They are not other researchers, they are practical railroad people, in particular the Transportation Department, other operating people, and to a very large extent the engineering people involved in the day to day work of the railroads.

In the matter of costs, Ted Rudback suggested that he had a pretty good handle on the cost of research, but I am not sure that is entirely true. There is the direct cost of doing a particular project. We likely must add to that a fairly considerable overhead of your own group and any other groups that may be involved in this work. There is also the cost of the failed projects, of projects that did not ever get anywhere for one reason or another. We could reduce the cost of research by reducing the number of failures through better liaison with the people that I define as the users. Research work can be done by researchers but it must be directed and coordinated by those people that are going to use the expected outcome.

I think that we in the railroads, and certainly CP Rail, are in a very difficult position right now with the emphasis on decreased staff. Some of those people in the Engineering and Operating departments that could spend time looking at these projects just aren't there anymore. Others are so busy putting out fires that they have no time to look at these sorts of projects, and I think we have lost. Is there some way in which the Engineering and Operating departments, not the Research departments, can be assigned time and staff to look into some of these projects. This would provide users to work with the people that do the research work.

P.J. DETMOLD: That is an excellent point, Doug. I think it makes sense as times get harder and more competitive for the industry to maintain research and development budgets. I think it would ease the task if we were to take the word "Research" out and say "Development" and not repeat the work that somebody else is doing. We have mechanisms for effective cooperation, the most obvious one being the AAR. We still seem to need to tie the things together. It is difficult to articulate because it is a multi-dimensional problem. We have these needs: we have cost elements that Kelly Arrey referred to which seem to be high enough to demand some research; we always have a shortage of funds; we have elements where we really need basic research; we have elements where all we really need to do is to put together technologies that have been around for a long time and apply them to solve our problems. Somehow we don't seem to be able to do it as an industry, as individual companies. I don't know quite why that is, and I have thought about it a good deal. We do seem to have this problem of collecting together our distilled wisdom as an industry in the first place to decide which way to go on the research course. This is very difficult to do and it is indeed true that in the very early stages, you very often don't have very good cost benefit analysis. You need a little bit of blind faith with to start.

Now I seem to have unwittingly produced some conclusions for this meeting and strangely I have produced them at exactly 12:01. There are two more things to say.

W. ELMARAGHY: There is one problem which I would like to raise (the question is easier posed than answered) which is fundamentally important for this type of development, and that is the cycle time for development. Kelly Arrey pointed out that it takes a very long time to prove a product, it takes a long time to develop it and a long time to test it, re-test it, and re-design it. For something as simple as two steering arms to improve the performance of the three-piece freight truck, it takes 15 years typically, and for larger projects it takes even longer. I think the question that needs to be addressed by TDC and the railways is how to shorten that cycle time. Private industry, the manufacturers, cannot develop new products that will not be sold for ten years in any significant quantities. Some of these manufacturers may be out of business before such a product is sold. In this age where we talk about JIT (just-in-time delivery), what about just-in-time product development and delivery of the product. If product development takes too long, perhaps it is not viable and the work should be terminated. I think this is an important question.

P.J. DETMOLD: Yes, I certainly would say "Amen" to that one.

N.E. RUDBACK: I think that is a particularly valid point and I would like to comment on it. TDC has had some recent experience in that area working in passenger vehicles. One was an attempt to do a relatively simple modification to a bus to make it operate on rail lines. The other is working with a bus manufacturer that has developed a new articulated bus. The difference is night and day between working with the rail mode and the road mode in getting new equipment developed, put into service and into the market place. The time and the difficulties it is taking on the rail side are a serious problem for the railway industry. There is no point in talking about innovation in five or ten years when your competition is doing it in one, two or three years. Bridging this gap between concepts, completing the development and marketing the product is something that must be addressed and moved ahead, otherwise I really question whether the railways are going to be able to keep competitive with road transportation.

P.J. DETMOLD: I have a question from Joe Kalousek.

J. KALOUSEK (NRC): I would like to comment to Mr. Walkington that, as there is no such thing as free lunch, there is no such thing as a failed research project. If you have an idea which you prove does not work, it does not mean that it was not worthwhile pursuing. The only thing that is wrong about the failure of a research project is that the results do not get published. Then other people come along with that good idea and spend money on repeating what some other person has learned. So, when are we going to have a seminar on the failed projects?

**W. ELMARAGHY:** I just would like to follow up my question and Mr. Rudback's answer to make sure I was not misunderstood. In addition to what he said, I am suggesting that the whole process of development and testing should be looked at as a project. The project objective would be to find out how the process can be accelerated and meet the needs of industry as well as the requirements of the railways. In other words, how can everything necessary be done in shorter period of time, including the things like accelerated testing where help in that regard is needed. There are facilities for accelerated testing in Ottawa and elsewhere.

**P.J. DETMOLD:** Thank you very much. I think we did understand your point and it is a very good one. Are there further questions?

**UNIDENTIFIED SPEAKER:** I would like to add to what Mr. Elmaraghy has said.

I agree that a company may not live 10 years on a new product if it is not being sold. Conversely, I think that the railways are going to be around for some time. It is their role to specify what areas most need research or development work and then let the researchers and suppliers present how they can best respond to these problem areas.

**P.J. DETMOLD:** That is certainly a point of view. I see no reason why an industry that is viable should not be able to devote the cash flow to keep itself going. I think we all agree that to continue in business we must exploit our advantages in the most effective manner. Where we have the difficulty is in the mechanism of how to do it, and we do seem to have some little friction that prevents us from doing it.

**N.E. RUDBACK:** I was going to ask Dick Pomeroy to make a comment, but I see he is ready to do it anyway. First I would like to question the statement that the railways will be here forever. I would like to be a little bit provocative. They said the rail passenger business would be here forever; they said the rail express business would be here forever. Now we see intermodal traffic threatened with doubles and triples from innovative industries. You may question how long this traffic is going to be there and extrapolate from there. The difficulties of getting rail innovations through to the market place are very serious and very important to the survival of the industry. Dick Pomeroy has had personal experience with this over a long period of time and it would be appropriate that he express his point of view as part of the supply industry.

**R. POMEROY (DSL Dynamic Sciences Ltd.):** I was just about at the limit where I could not sit still. There is a thread running through our comments which has something to do with focus. I think some of us are struggling with what parts of this thing that we ought to focus on. Focus is really the key.

Mr. Chairman, you made some comments about pure research being research with no clear objective. I have a completely different point of view. I think all research has to have a clear objective. Otherwise it can fail, because you end up drifting along, chasing will-of-the-wisps and prolonging projects instead of saying yes, that idea worked or didn't, and then getting on with another specific objective. That is the only way the thing can come to some kind of successful conclusion. I would apply that to everything including deep space probes. They have to have some specific objectives, even if not everyone agrees with them.

From a more political, philosophical, point of view on government's involvement in R&D, it is particularly important that there be a focus. It should be a somewhat longer term focus than the annual bottom line orientation of most commercial companies. If you look at the model that Japan presents to us of government involvement in R&D, they tend to set up plans or programs with fairly long duration and a very specific objective. I think that is the key to whatever success they realize in those projects. There is a real role for government in providing both the long-term objective and also the continuity that companies like ours have found to be very, very valuable in their lean times when we cannot sell anything.

I started out in more or less pure research, (although I always had purpose) and after getting into the supply industry, have come to be much more commercially orientated. After a few years of involvement with government assistance I came to the point of view that I don't want it unless I can see, at the end of it, being able to send a product brochure to the printers. That was my way of keeping myself and my enterprise honest. I really hardened that viewpoint considerably in the last few years. Now I won't take on any project unless I can sit down with a potential customer and, (endorsing very strongly what was said previously), have him tell me that if I carry out the project, he will buy the resulting product. I think that for a person in my position to do anything else is inviting disaster to my company and myself. Now not everybody is in that position, but I think that the embryonic supply industry in Canada really needs that kind of a link with the customers. It has to be very specific. We can't go off with the invitation of, "That is of interest, go and make one and we will see if we like it". There is too much money involved and it is just too speculative for us to do so. Jointly we can be much more successful if we can be specific.

If we can be specific in our objectives and come to our conclusions fairly quickly as to whether what we are trying to do works or not, then we can get on and advance ourselves. It may be a little like one suggested key to success in the stock market: take a short term view of your investment and if it does not do what you wanted it to, get out of it quickly. That might or might not be the way to success in the stock market, but I certainly believe that it is the key to success in research and development of the sort we are doing. It has to have an economic aspect to it, and it is an important aspect. Canada is an economic unit and I think it is useful for us to think of ourselves in those terms, particularly with respect to

Federal Government assistance. It helps to put our supply industry, the Canadian railways and the Canadian Government's investment in all this into some perspective. Let's think of ourselves as an economic unit in the world, and we have to be viable in order to stay around.

P.J. DETMOLD: Thank you. I certainly did not intend to suggest that research is purposeless. The point I was trying to make is that there are people who look at subjects in a more abstract way and very often the outcome of what they do is not in sight when they do it. I think the best recent example was the invention of the laser. Now there is a whole new science of optronics, but when the laser was invented back in 1959, I don't think they had any idea that it would have this kind of application because there wasn't the high purity glass available to apply to optronics. If you want to go murh further back you get examples involving radar and even the original steam engine. There are a number of major inventions for which the most widespread use was not in sight at the time thy were invented. It seems to me that in a community you need to have some people looking at things in an abstract way and some people looking at the use for things in a much more hard-boiled commercial way.

I think the feeling of this meeting is that research must be hard-headed and commercial. The question is how do you get to the point when it becomes hard-headed and commercial. How do you bridge this gap between the abstract technologies and the application? Do we have any further points on this?

I see we have run a little overtime. I personally enjoyed this discussion and I hope you have. I think it has given the seminar a pattern. I don't see anyone else wishing to speak so I will now thank Ted and TDC very much for having the seminar. It was a very good idea. We have discussed subjects of importance to all of us and even if we haven't solved all of the world's problems, at least we have identified some of the problems a little more closely than we had previously. I would like to thank the chairmen of the technical sessions at this table and all our speakers. I think we have had a very good meeting. Thank you all for coming and making it successful. We stand adjourned.

MEETING ADJOURNED

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